Land Draining

A Handbook for Farmers

ON THE

PRINCIPLES AND PRACTICE

OF

FARM DRAINING

By MANLY MILES, M. D., F. R. M. S.

Author of "Stock Breeding;" "Silos, Ensilage and Silage," etc., etc.

ILLUSTRATED

NEW YORK
ORANGE JUDD COMPANY
1892

Preface.

A book on farm draining is evidently needed at the present time, to bring within reach of practical farmers the established facts of science relating to the principles and advantages of thorough drainage, and the best and most economical method of making farm drains.

Under the present conditions of American farm practice, one of the most prominent defects in the prevailing system of management appears to be a lack of attention to thorough drainage as a means of diminishing the cost of production, and insuring uniformly remunerative returns in crop growing, by increasing the fertility of the soil, and avoiding the losses from unfavorable seasons. The manifest neglect of this important branch of rural economy by the majority of farmers is undoubtedly owing, to a great extent, at least, to the frequent failures observed in draining, from the practice of imperfect methods, and vague, or incorrect notions, in regard to the real advantages to be derived from draining.

This is not surprising, as attention has been turned in other directions, and the most valuable contributions to the principles of drainage, of late years, have been confined, in the main, to periodicals and reports not generally accessible to farmers, and there is no book on this special subject in which may be found a description of the best method of making tile drains, or an adequate discussion of the latest developments of science in their relations to the principles of drainage. Many of the

maxims in draining, of but a few years ago, have become obsolete, and more consistent methods have been adopted in the best modern practice, while the progress of science has extended our knowledge of correct principles, and made clear many details in regard to the most favorable conditions for growing crops, which are of great practical importance.

In this *Handbook for Farmers,* the aim has been to present the leading facts of practical significance, in connection with a popular discussion of the applications of science, and the results of experiments relating to draining have been summarized in tables in convenient form for reference, which furnish ready answers to many of the economic questions that will be suggested to the intelligent farmer.

An outline of the history of draining is given to illustrate the progress of discovery and invention in developing correct principles of practice, and the directions for laying tiles, which are the results of an extended experience in draining under widely different conditions, are confidently recommended as a decided improvement on former methods.

Lansing, Mich., 1892.

CONTENTS.

CHAPTER I. Page

General Principles ... 1

CHAPTER II.

Water in Soils and Conservation of Energy ... 24

CHAPTER III.

Rainfall, Drainage and Evaporation ... 35

CHAPTER IV.

Energy in Evaporation ... 58

CHAPTER V.

Advantages of Draining Retentive Soils ... 70

CHAPTER VI.

Progress of Discovery and Invention ... 96

CHAPTER VII.

Location and Plans of Drains ... 130

CHAPTER VIII.

Quality and Size of Tiles ... 139

CHAPTER IX.

How to Make Tile Drains ... 157

CHAPTER X.

Drains in Quicksand, and Peat ... 177

CHAPTER XI.

Outlets and Obstructions ... 184

CHAPTER I.

GENERAL PRINCIPLES.

The rapid growth of science, and the development of the mechanic arts which have made possible the unprecedented activity in the industries during the past quarter of a century, have brought about economic changes in methods of production, which must be taken into consideration in attempts to improve the practice and increase the profits of agriculture.

From the intense competition in farm products of all kinds, arising from the extraordinary development of facilities for cheap transportation, the farmers of the United States are directly interested in every means of diminishing the cost of production, to enable them to hold a commanding position in the world's markets, and obtain remunerative returns for their labor, without impairing the value of their invested capital. The business methods that have been found necessary to insure success in other pursuits must be adopted, and attention must be given to every available means of increasing the productiveness of the soil and making the labor expended on it more effective, while the losses resulting from bad seasons must be reduced to a minimum by the intelligent direction and control of the forces of nature.

One of the first steps in the direction of improved methods of farm practice is to put the soil in a condition to yield the best net returns from the elements of plant food which it naturally contains, or that may be applied to it in the home supplies of manure. The questions that may arise in regard to artificial, or purchased fertility,

are of secondary importance to the majority of American farmers, and the leading problem for them to solve is to obtain the best returns from the elements of production already within their control.

Among the available agencies for bringing about this desirable conservation and utilization of the elements of profitable crop-growing on a large proportion of the farms of this country, thorough drainage is the most important, as upon it will depend the successful application of other means of increasing productiveness, including thorough tillage and manures, which are relied upon to increase the net income that may be derived from the aggregate of farm operations.

In order to lay a foundation for the intelligent discussion of the advantages of thorough drainage it will be necessary to briefly review some of the conditions that are essential to the health and well-being of the crops grown on the farm. The results of scientific investigations are suggestive, and the knowledge that has been gained of the laws and processes of vegetable nutrition and growth must be recognized as of great practical value in farm economy, when their relations to details of practice are clearly understood.

The uniform certainty of results obtained in all operations in other industries can only be realized in agriculture when the practice of the art is based on consistent principles, in harmony with those natural laws which it is the mission of science to discover and investigate. In dealing with the different forms of life with which the farmer is chiefly concerned, the best results can only be obtained by a strict conformity to physiological laws, the practical significance of which may readily be learned and appreciated, without any profound knowledge of the science of physiology.

Clear and consistent notions of the philosophy of farm drainage can only be secured by an examination

of the known facts relating to the nutritive activities of plants and their relations to the soil and its contained moisture, to ascertain what special conditions are likely to interfere with their normal processes of growth. The intelligent farmer will not be satisfied with the simple statement that the draining of retentive soils makes them more productive, but he will inquire how this result is brought about, and the knowledge he may acquire in tracing to their source the conditions that favor the vigorous growth of his crops, will be of value to him in suggesting many details of practice that may be profitably adopted in his general system of farm management.

We cannot, of course, in this connection, attempt a full discussion of the physiology of plants, and attention will only be directed to some of the leading facts in this department of science, that have a direct relation to the principles of farm drainage.

Physiologists tell us that a very large proportion of the dry substance of plants is derived from the atmosphere, but it is well understood that the atmospheric supplies of plant food are only made available when their roots are enabled to take from the soil, under favorable conditions, the comparatively limited amount of nutritive materials it is their function to furnish.

From a practical standpoint it is, therefore, a matter of the first importance to provide suitable soil conditions to promote the functional activities of the roots of plants, as they have direct relations with the part performed by the leaves in appropriating from the atmosphere materials that constitute the great bulk of the dry substance of the plant.

Dr. Gilbert makes the statement that in the Rothamsted experiments, "by the application of nitrogen to the soil, for mangels, there was, in many cases, an increased assimilation of about one ton of carbon per

acre, from the atmosphere," and that one pound of nitrogen as manure for mangels gave an increase of over twenty-two pounds of sugar, derived almost exclusively from the atmosphere. With wheat and barley for twenty years there was an increase of from fourteen to twenty-two pounds of carbon in the crop for each one pound of nitrogen in the manure. The results here presented are in strict accordance with other known facts in vegetable physiology, which it is unnecessary to notice, and we cannot avoid the conclusion that soil conditions have a direct influence on all of the nutritive processes of plants, and that their chemical composition furnishes no index of their requirements in regard to the food constituents that may be profitably applied in the form of manures.

In the growing of crops, as well as in the care of his animals, the farmer is dealing with living organisms, and it is not sufficient to furnish the food elements required in building tissues, but he must also provide conditions that are in every way favorable for the exercise of their vital activities, on which the appropriation and assimilation of their food directly depends.

Conditions of Plant Growth.

In common with other living organisms, our farm crops require certain conditions of environment for their active growth and perfect development, and among those which the farmer can, to a greater or less extent, control, may be enumerated as essential—a favorable temperature, a proper supply of moisture, and a supply of appropriate food. In the absence of, or any marked deficiency in, either of these conditions, the plants cannot thrive. These conditions must be studied in detail, as they have a direct relation to the subject of farm drainage.

Temperature. Plants do not grow in the spring, and seeds do not germinate until the soil is sufficiently

warmed by the sun and the heat liberated in the processes of soil metabolism. Each crop is adapted, by its inherited habits, to a certain range of temperature peculiar to itself. There is a minimum temperature at which all growth ceases, a maximum beyond which the plant cannot live, and between these extremes there is an optimum temperature that is most favorable for rapid growth. Any agency, or condition of the soil that tends to lower the temperature from the optimum point must, therefore, retard the processes of growth and development, no matter how favorable other conditions may be.

The range of temperature within which plants can grow lies between the freezing point and about 122° F. The optimum temperature in any particular case can only be stated approximately, as the results may be modified by other conditions. According to the experiments of Sachs, Köppen and Alphonse de Candolle, wheat and barley do not sprout if the temperature is below 41°, and the most rapid growth was made at about 84° F. Maize required a temperature of at least 48° for germination, and the most rapid growth of the roots was made when the temperature was about 90° to 93°.*

Carbon, which constitutes about one-half of the dry substance of plants, is appropriated by chlorophyll (the green coloring substance of plants), in the presence of light, from the small percentage of carbonic acid present in the atmosphere. The larger part of the carbon assimilated by plants from carbonic acid is obtained by the leaves, but the air permeating cultivated soils contains a larger percentage of carbonic acid than the normal atmosphere, and this is absorbed by soil water, and may therefore gain access to the plant through the roots. The presence of chlorophyll, however, appears to be necessary for the assimilation of the carbon from the

*Sachs' Text Book of Botany, p. 750.

carbonic acid introduced through the roots, as well as by the leaves. The lowest temperature at which chlorophyll was formed in maize was observed, by Sachs, to be between 43° and 59°.* When the temperature is too low for the active formation of chlorophyll, as in cold, backward spring months, the pale appearance of the plants indicates a defective power of appropriating carbon from the atmosphere. The summer temperature in England is barely sufficient to mature wheat and barley, and Indian corn, which requires a higher temperature, cannot be grown as a farm crop.

Moisture. When growing, or in the green state, from about 68 to 88 per cent. of the weight of farm crops is water, and the remaining 12 to 32 per cent. is referred to as dry substance. The water contained in the crop, however, represents but a small part of that which is made use of in its processes of growth. The roots of a healthy and rapidly growing plant are constantly absorbing water from the soil, which is finally exhaled by the leaves, and disappears, in the form of vapor, in the atmosphere. A circulation of water through the tissues of the plant is thus maintained for the introduction and distribution of the inorganic nutritive materials derived from the soil. From this it will be seen that the amount of water required by farm crops is in fact very much larger than would be suspected by those who are not familiar with these well known processes in the nutrition of plants.

In a careful series of experiments made at Rothamsted, it was found that from 250 to 300 pounds of water was exhaled by field crops, for each pound of dry substance formed and stored up by the plants. "Hellriegel (at Dahme, Prussia) found that summer wheat and rye, oats, beans, peas, buckwheat, red clover, yellow lupines and summer colza, on the average, exhaled three hundred

*Sachs' l. c., p. 651.

grams of water for one gram of dry matter produced, above ground, during the entire season of growth, when stationed in a sandy soil."* It is probable that field crops, from their more vigorous growth and active powers of assimilation, may exhale a larger amount of water than plants under the artificial conditions required in exact experiments. Lawes and Gilbert estimate the average amount of dry substance produced on some of their experimental wheat plots at 5,600 pounds per acre, and this would involve the exhalation of over 800 tons of water. Estimated on the same basis, a crop of wheat of 25 bushels per acre would exhale, in its processes of growth, more than 500 tons of water, and a crop of one acre of Indian corn, of 60 bushels, would exhale about 960 tons of water, equivalent to more than 8.5 inches of rainfall.

The absolute amount of water in the soil that is most favorable for the growth of plants can only be approximately stated, as it will probably vary with the character of the soil, the kind of crop grown, and atmospheric conditions influencing evaporation.

"Hellriegel experimented with wheat, rye, and oats, in a pure sand mixed with a sufficiency of plant food. The sand, when saturated with water, contained 25% of the liquid." The results are given in the following table, the weights being in grams.

TABLE 1.

WATER IN SOIL AND YIELD OF CROPS.

WATER IN SOIL.		Y'LD OF WHEAT.		YIELD OF RYE.		YIELD OF OATS.	
In per cent. of soil.	In p.c. of retent'e power.	Straw and chaff.	Grain.	Straw and chaff.	Grain.	Straw and chaff.	Grain.
2½-5	10-20	7.0	2.8	8.3	3.9	4.2	1.8
5-10	20-40	15.1	8.4	11.8	8.1	11.8	7.8
10-15	40-60	21.4	10.3	15.1	10.3	13.9	10.9
15-20	60-80	23.3	11.4	16.4	10.3	15.8	11.8

"In each case the proportion of water in the soil was preserved within the limits given in the first column

* How Crops Grow, 1890 ed., p. 311.

of the table, throughout the entire period of growth. It is seen that in this sandy soil 10-15 per cent. of water enabled the rye to yield a maximum crop of grain, and brought wheat and oats very closely to a maximum crop. Hellriegel noticed that the plants exhibited no visible deficiency of water, except through stunted growth, in any of these experiments. Wilting never took place except when the supply of water was less than 2½ per cent."*

As farm crops will not grow well in a wet soil, it must be evident that the soil must be well pulverized and porous, and readily permeable to moisture, so that healthy roots may be distributed throughout its entire mass, to enable them to gather the large amount of water they require from the moist particles that represent the normal conditions of a productive soil. The capillarity of soils or permeability to moisture, so that a moderate but continuous supply is furnished to the growing crop, must then be recognized as an essential condition of fertility.

Food Supply. The roots of farm crops obtain from the soil certain materials that are needed in their constructive processes, among which are: nitrogen, chiefly in the form of nitric acid, or, to a limited extent, perhaps as ammonia—free oxygen from the air permeating the soil—and the mineral constituents that appear as ash when the plant is burned.

The larger roots serve simply as supports to the plant, or, in some cases, as stores of nutritive materials; while the absorption of plant food is exclusively carried on by the slender, thin-walled fibrils, or fine branches, forming the ultimate subdivisions of the larger roots. In most cases the absorbing surface is materially increased by numerous still more delicate cells, called root-hairs, which are thickly distributed near the end of

---

* How Crops Feed, pp. 215-216.

the fibrils. As the root fibrils increase in length, feeling their way, as it were, between the particles of soil, the older root-hairs disappear and new ones are formed a short distance behind the slender growing tip of the fibrils, and, in a vigorous, healthy plant, these delicate absorbing organs are found to penetrate every available space between the particles of soil.

The extent of these absorbing fibrils and root-hairs would not be observed in a careless examination, as most of them, under average conditions, are left in the soil when the plants are pulled up, the larger roots, only, remaining attached to the stalk. Hellriegel estimated the aggregate length of the roots of a single barley plant at one hundred and twenty-eight feet, and of an oat plant at one hundred and fifty feet, and he found that but a small fraction of a cubic foot of soil sufficed for this extended root development.* Under suitable conditions, the roots of a growing plant may be observed under the microscope, and the slender fibrils and root-hairs can then be seen closely in contact with each particle of the soil. These facts furnish a ready and simple explanation of the injurious effects of drainage water when retained in soils. These delicate absorbing organs of the roots of plants are not fitted for an aquatic life, and they readily succumb under the encroachments of standing or drainage water in soils. Their function is to absorb free oxygen, as well as the mineral constituents of plant food, and air must be allowed to circulate between the soil particles, to furnish the needed supply. When the space between the particles of soils is filled with drainage water the air is excluded, the supply of free oxygen cut off, and the active agents of absorption cannot live under these abnormal conditions.

We must, then, include among the essential conditions of vigorous growth in plants, a finely pulverized

* How Crops Grow, 1890 ed., p. 265.

soil free from drainage water, that will permit and encourage the free ramification of these delicate organs of absorption, in free contact with air, and the moist surface of the soil particles.

Soil Metabolism. Soils are not an inert mass of matter from which plants passively obtain their food supplies. All soils that are, or may be made, fertile, are constantly undergoing change, and the transformations taking place in the arrangement, or relations of their constituents, may be favorable, or otherwise, to the well being of the crops growing in them, according to the conditions present for the time being. The aggregate of chemical, physical and biological changes, or transformations that take place in soils, are conveniently expressed by the general term *metabolism,* without attempting to distinguish between them, which, in the present state of knowledge, would, in most cases, be impossible.

For a more detailed account of the purely chemical and physical changes taking place in soils, than, for lack of space, is here given, the reader is referred to readily accessible works, in which they are more or less fully discussed.*

Biological Factors. Recent investigations, however, tend to show that biological activities are important, and, perhaps, in some cases, dominant factors in soil metabolism, and in their relations to our present subject of farm drainage they require notice in greater detail.

All processes of fermentation and putrefaction are now known to be caused by living organisms, each of

---

*Master's *Plant Life on the Farm,* and Warington's *Chemistry of the Farm,* are admirable popular elementary works that may be profitably consulted by the general reader. For the advanced student Johnson's *How Crops Feed,* and *How Crops Grow,* new ed., 1890, and Storer's Agriculture, 2 vols., will be more satisfactory, from the more detailed illustration of the principles under discussion.

which performs a specific *rolê* in tearing down and disintegrating organic substances in their processes of nutrition. Yeast, a minute plant, of which there are several species, is the type of the true alcoholic ferments. The lactic, butyric, acetic, and other ferments, belong to the group of minute organisms popularly known as bacteria, or microbes. To the same group belong the various ferments concerned in the complex processes of putrefaction.

The rotting of manures and the disintegration of organic matters in the soil are brought about by a series of micro-organisms that succeed each other with the change of conditions presented in the course of the putrefactive process. One species, beginning the work of putrefaction, after taking the supplies of food fitted for its nourishment, leaves a residual mass that is better suited to the requirements of some other species which succeeds it, and this, in turn, for the same reasons, is succeeded by another form better fitted for the new conditions, and these changes in the active agents of decay are repeated, wholly, or in part, until the entire mass is reduced to its elements, or simple binary compounds. Each species requires, for the exercise of its vital activities, certain conditions of environment, and as these are constantly changing as the putrefactive process proceeds, the microbes that, for the time being are best adapted to the prevailing conditions, become the dominant species. This is, in fact, but a phase of the "struggle for existence," and "survival of the fittest," that is now recognized as an important factor in the evolution of organic beings.

Agricultural plants cannot make use of organic substances as food, but in the processes of disintegration, to which they are subjected in the soil, plant food is liberated in an available form; but in case no growing plant is present to appropriate it, the next series of changes, brought about by the accession of other species

of microbes, may transform what is valuable plant food to a condition unfitted for the nutrition of plants. Soil exhaustion cannot, therefore, be measured by the amount of the chemical elements of fertility removed in crops. In the absence of growing plants a loss of fertility may not only take place through the agency of microbes, but it may be washed out of the soil by rains, or locked up in more stable compounds with other soil constituents. Summer fallows were supposed to increase the available elements of fertility in the soil, but the soluble materials formed in the metabolism of fallow soils are liable to be washed out by rains, in the absence of growing plants to make use of them.

Schloesing and Muntz made the notable discovery, in 1877, that nitrification is caused by microbes, and this led to further investigations, by numerous observers, in regard to the agency of these organisms in preparing plant food, which have proved to be of great practical interest. Nitric acid, in combination with bases, forming nitrates, seems to be the favorite form of nitrogenous food for farm crops, and this is provided by nitrifying microbes, under suitable conditions for the exercise of their processes of nutrition, from the nitrogen of the organic substances, and ammonia of the soil and manures, and from the atmospheric nitrogen permeating the soil.

Nitrification is carried on very slowly at temperatures but little above the freezing point, and then rapidly increases as the temperature is raised to an optimum of 90° to 99°, when the organisms are most active. At higher temperatures nitrification diminishes, and ceases entirely at 125° to 131°. At Rothamsted thirty-seven days were required for the nitrification of the substances under experiment at 52°, while it was completed in eight days at a temperature of 86°. Schloesing and Muntz state "that at 99° nitrification is ten times more rapid than at 57°."

We have already noticed the relations of temperature to the vigorous growth of the plants themselves, and it now appears that the supplies of plant food are likewise influenced by the temperature of the soil, through its effects on the living organisms that prepare it. The atmosphere is composed of a mixture of gases consisting, by volume, of 20.96 per cent. of oxygen, 79.00 per cent. of nitrogen and 0.04 per cent. of carbon dioxide (carbonic acid), to which should be added a variable amount of the vapor of water and minute quantities of combined nitrogen, in the form of nitric acid, ammonia, and organic matters, which are washed out by rains and thus carried to the soil. The nitrogen annually added to the soil from this source, at Rothamsted, is estimated not to exceed four or five pounds per acre.

When the discovery was made of the composition of the atmosphere it was at once supposed that the vast envelop of free atmospheric nitrogen was the main, or sole, source of the nitrogen of plants. Experiments by Boussingault, in France, and by Lawes and Gilbert, at Rothamsted, in England, however, showed that free atmospheric nitrogen was not appropriated by plants, and that their supplies of nitrogen were obtained from the soil. Notwithstanding this conclusive evidence to the contrary, it is a popular notion, indorsed even by some chemists, that leguminous crops (clover, beans, peas, etc.) obtain their nitrogen directly from the atmosphere. The practical inferences from this erroneous theory are misleading, as they ignore the importance of soil conditions on the supplies of nitrogenous plant food.

It was likewise shown in the Rothamsted experiments that, while leguminous plants removed from the soil much larger amounts of nitrogen than the cereals, they were not benefited by nitrogenous manures, which had a marked influence in increasing the growth of the cereals. It was also found that on land where cereal

crops failed to grow from a deficiency of soil nitrogen, large leguminous crops were grown containing much more nitrogen than a heavy crop of cereals. It was, in fact, evident that leguminous crops obtained nitrogen in some way, or from some source, that was not available for the cereals.

An explanation of these anomalous results has been furnished by recent experiments, and it is now known that the tubercles, or nodules, that have been frequently observed on the roots of leguminous and some other plants, are caused by microbes, and that, through their agency, the free nitrogen of the atmosphere permeating the soil is appropriated and made available, as combined nitrogen, in the nutrition of the plants with which they are associated.

Some of the experiments leading to these conclusions will be of interest here, as they have a direct bearing on the subject of farm drainage in its relations to soil metabolism. Hellriegel, in experiments with agricultural plants, in pots filled with washed quartz sand, to which nutritive solutions containing no nitrogen were added, found that in some of the pots the plants grew luxuriantly, while in others the growth seemed to be limited and determined by the amount of nitrogen contained in the seed. He observed numerous nodules on the roots of the plants that made a good growth, while there were none on the roots of the plants of limited growth. A probable relation of the root-nodules to the supply of nitrogen obtained by the plants was suggested and made the subject of investigation.

Experiments were planned "to determine whether, by the supply of the organisms, the formation of the root-nodules and luxuriant growth could be induced, and whether, by their exclusion, the result could be prevented. To this end he added to some of a series of experimental pots 25 c.c. (0.88 ounces), or, sometimes,

50 c.c. (1.76 ounces) of a turbid extract of a fertile soil, made by shaking a given quantity of it with five times its weight of distilled water. In some cases, however, the extract was sterilized (by the application of heat, to destroy all living organisms). In those in which it was not sterilized there was almost uniformly luxuriant growth and abundant formation of root-nodules; but with sterilization there were no such results. Consistent results were obtained with peas, vetches and some other Papilionaceæ; but the application of the same soil-extract had no effect in the case of lupines, seradella and some other plants of the family which are known to grow more favorably on sandy, than on loamy, or rich humus soils. Accordingly he made a similar extract from a diluvial sandy soil where lupines were growing well, in which it might be supposed that the organisms peculiar in such a soil would be present; and on the application of this to nitrogen-free soil, lupines grew in it luxuriantly and nodules were abundantly developed on their roots."

At Rothamsted* experiments were made on the same lines, in 1888, with peas, blue lupines and yellow lupines; and in 1889, with changes suggested by the experiments of the preceding year, they were repeated with "peas, red clover, vetches, blue lupines, yellow lupines and lucern," under the following conditions: For the lupines and lucern special glazed earthenware pots were made, fifteen inches deep and six inches in diameter, and for the other plants the pots were seven inches deep and about six inches in diameter. "There were four pots of each description of plant." Three of these were filled with clean-washed quartz sand, to which was added 0.1 per cent. of the ash of the plant to

*A more detailed account of these experiments, particularly in their relations to crop rotations, will be found in Popular Science Monthly for Feb. 1891, p. 691.

be grown, and 0.1 per cent. of calcium carbonate. To destroy all living organisms in this prepared soil it was kept for several days at a temperature of about 212°. A fourth pot for the lupines was filled with soil from a field where lupines were growing, to which was added 0.01 per cent. of lupine ash. A fourth pot for each of the other plants was filled with garden soil.

Seeds were sown to secure a uniform stand of two plants in each pot, and all were watered with distilled water. To one of the three pots of washed and sterilized quartz sand, for each kind of plant, no further addition was made, while the other two were inoculated, or seeded, with a soil-extract prepared as in Hellriegel's experiments. For the lupine pots the extract was prepared from the soil of a field where lupines were growing, and for the other plants the extract was prepared from a garden soil like that filling the fourth pot of each series. An analysis of these soil extracts showed that the elements of plant food they contained were so small in quantity that they could be safely ignored in summing up the results, and the effects of the extracts on the soil could only be attributed to the microbes with which they were seeded.

The results of these experiments may be tabulated, as in table 2, showing the height of the two plants in each pot.

TABLE 2.

CONDIT'N OF SOIL IN POTS.	HEIGHT OF PLANTS IN INCHES.		
	Peas.	Vetches.	Yellow lup'ns.
Prepared quartz sand, not inoculated	8¼-8½	11¼-10½	1½-2½
Prepared quartz sand, inoculated	14-50½	52½-67	24-18
Prepared quartz sand, inoculated	52½-50½	61½-51	24-8
Garden soil for peas and vetches—field soil for lupines	Plants smaller than in the inocul'd pots.	53-36	16-18

The peas, vetches and yellow lupines were harvested at the close of the season, and analyzed to ascertain the

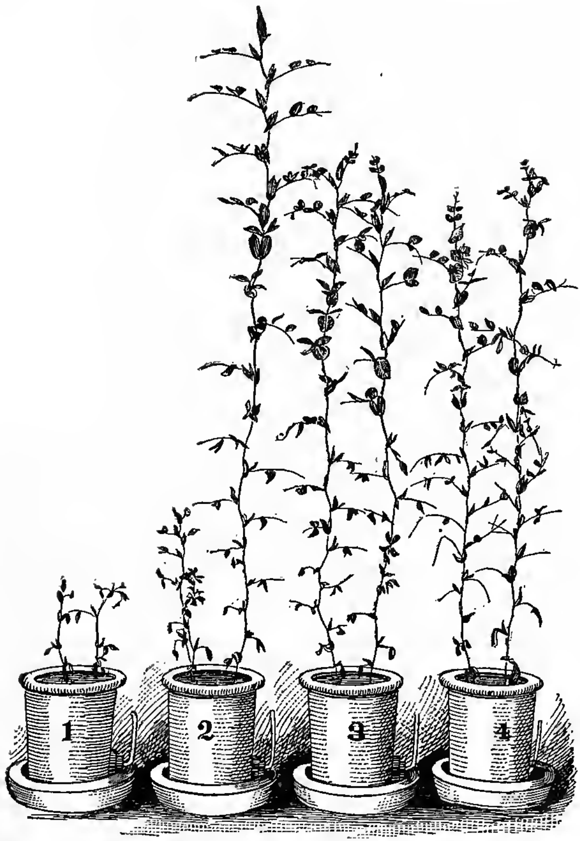


FIG. 1. PEAS.*

*Pots 1, 2 and 3 were filled with the prepared and sterilized quartz sand. Pot 1 was not inoculated. Pots 2 and 3 were inoculated with the microbes of a garden soil extract. Pot 4 was filled with a garden soil.

amount of nitrogen assimilated, and the nodules and root development were carefully examined. The blue lupines failed to grow, and the red clover and lucern were reserved for a second year's growth. Copies of the photographs of the plants, taken when harvested, are given in figs. 1, 2 and 3.

The limited growth of the plants in the sterilized quartz sand that was not inoculated with soil extract (pots 1, 9 and 17) was apparently determined by the amount of nitrogen in the seed, the soil itself being practically barren. There was but little root development in these pots, and no root-nodules could be found.

In the pots of sterilized quartz sand seeded with the microbes of a soil extract (pots 2 and 3, fig. 1—10 and 11, fig. 2, and 18 and 19, fig. 3), there was, on the other hand, abundant root development and numerous root-nodules. On the roots of the plants in the garden soil (pots 4, fig. 1, and 12, fig. 2), and on the roots of the lupine in the field soil (pot 20, fig. 3) some root-nodules were found, but they were not as numerous as on the roots in the inoculated quartz sand.

The figures clearly show, as well as the tabulated results, that the growth of plants in a sterile quartz sand was materially increased by inoculation with the microbes of a soil extract. Another still more striking and suggestive fact is the failure of the plants in the garden and field soils to make as vigorous growth as was made in the inoculated quartz sand. These natural soils undoubtedly contained very much more of all of the elements of what we are accustomed to look upon as plant food, than the quartz sand, which, when seeded with microbes, proved to be the most productive, notwithstanding its original poverty of constitution.

It is evident, from the results of these experiments, that the chemical composition of soils does not furnish evidence of fertility, even under conditions that appear

FIG. 2. VETCHES.*

*Pots 9, 10 and 11 with prepared quartz sand, sterilized. Pots 10 and 11 inoculated with garden soil extract. Pot 9 not inoculated. Pot 12 with garden soil.

to be favorable for the growth of plants, and that micro-organisms in the soil are important factors in the elaboration of plant food.

From what we now know in regard to soil metabolism and vegetable nutrition, the comparatively limited

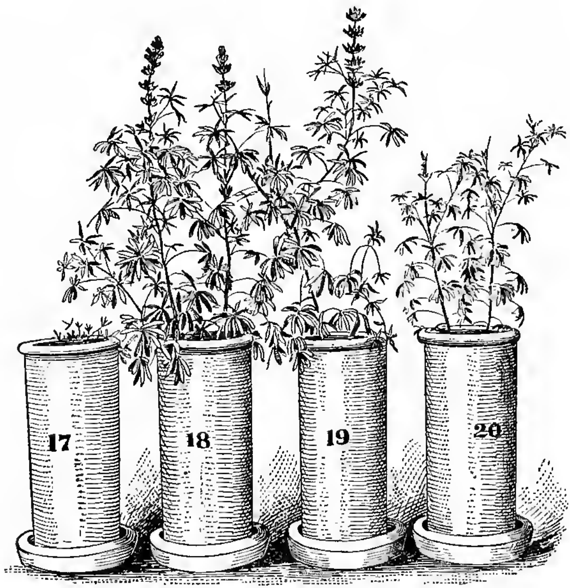


FIG. 3. YELLOW LUPINES.*

growth of the plants in the garden and field soils (pots 4, 12 and 20) can only be attributed to defective biological conditions. That the microbes, concerned in the appropriation of free nitrogen from the air permeating

*Pots 17, 18 and 19 were filled with the prepared quartz sand. Pots 18 and 19 were inoculated with the microbes of a field soil extract, and pot 17 was not inoculated. Pot 20 was filled with soil from a field where lupines were growing.

the soil, found less favorable conditions for growth and development in the garden and field soils, is shown by the smaller number of nodules on the roots of the plants growing in them, as already noticed, and yet it must be remembered that the sterile quartz sand was seeded with the microbes in a water extract prepared from these same natural soils.

Again, the garden and field soils had a great apparent advantage over the prepared quartz sand in the combined nitrogen of the organic matters they contained; but this was not made available, from the lack of suitable conditions for the nitrifying microbes that were required to prepare it for the nutrition of plants, or from defective conditions for root distribution, or both, acting together. These biological defects of the garden and field soils were probably caused by physical conditions resulting from the manner in which they were packed in the pots, or by diminished porosity arising from the method of watering.

Thus far, the relations of microbes to soil metabolism have been considered with reference to the nitrogen supplies of plant food, but there is evidence that the mineral constituents of soils undergo transformations resulting from the nutritive processes of microbes and the roots of plants. In my own experiments with soil microbes, the glass tubes in which cultures were made, under certain conditions of defective supply of lime and potash in the culture solutions, have been deeply etched as the result of their activities, and they also readily obtained their supplies of lime and potash from solid fragments of gypsum and feldspar.

As a further illustration of biological activities in soil metabolism we should not fail to notice that the roots of plants themselves aid in the disintegration of soils, through their selective and digestive action upon the particles of soil with which they are in contact. In

Sachs' well known experiments the details of the root systems of beans, squashes, maize and wheat were clearly traced on polished plates of "marble, dolomite (carbonate of lime and magnesia), magnesite (carbonate of magnesia) and osteolite (phosphate of lime)," by the fibrils and root-hairs that corroded the surfaces on which they were growing.* Dietrich found that the roots of "lupines, peas, vetches, spurry and buckwheat assisted in the decomposition and solution of the basalt and sandstone," presented for their action in the form of coarse powder.†

In water-culture experiments the plants appropriate the nitric acid of nitrate of potash, leaving behind the potash; and "when ammonium chloride is employed to supply maize with nitrogen, this salt is decomposed, its ammonia assimilated, and its chlorine, which the plant cannot use, accumulates in the solution in the form of hydrochloric acid to such an extent as to prove fatal to the plant."‡ Whether the decomposition of these compounds is brought about directly by the roots of the plants themselves, or through the agency of micro-organisms in the culture solutions, has not been determined, but in either case these changes must be recognized as the result of biological activities, that are of interest in their relations to soil metabolism.

In every direction we find evidence that other factors than the food supply of plants must be considered as having an influence on their vigorous growth and ultimate composition. From their inherited feeding habits, and the relations of the soil constituents to the metabolism and demands of their tissues at the time, plants seem to have the power to "take what they want, and when they want it, and are not induced to take more by the addition of larger supplies."

* Sachs l. c., p. 625—How Crops Feed, p. 326.

† How Crops Feed, p. 327.

‡ How Crops Grow, new ed. 1890, pp. 184, 403.

In the Rothamsted experiments with wheat and barley grown for a long series of years on the same land, under widely different conditions of manure supply, it was found that the percentage of nitrogen, potash and phosphoric acid in the dry substance of the grain was influenced more by the season than by the supply of these constituents in the soil, and that in favorable seasons, for the perfect maturing and ripening of the grain, its composition was quite uniform on the different plots, which presented marked contrast in the amount of the food constituents contained in the soil. There were greater variations in the composition of the straw, but the influence of seasons was manifestly more significant in producing them than differences in the composition of the soils.

From this review of some of the biological factors of soil metabolism and vegetable nutrition it must be seen that the abundant supply of the elements of plant food in soils will not render them fertile or productive, unless favorable conditions are provided for the normal exercise of the vital, or physiological, activities of the living organisms (roots of plants and soil microbes) on which the selection and elaboration of the nutritive materials, in an available form, so largely depend. We can now profitably consider the relations of the different forms of water in the soil to these factors of soil metabolism and plant growth.

CHAPTER II.

Water in Soils, and Conservation of Energy.

Water in the soil may be free, or in combination with its constituents. Free soil water may be conveniently considered under three conditions, which have been designated by Professor S. W. Johnson as *hydrostatic*, *capillary* and *hygroscopic.**

Hydrostatic, or Drainage water is that which may percolate through the soil by gravitation, and be removed by draining, or, in case of undrained soils with a retentive sub-soil, it may be retained, forming the "standing water" of the soil. The surface of this drainage water in the soil is called the *water table,* to which we shall frequently refer.

Capillary Water is held in contact with the particles of soils by capillary attraction, and gives the appearance of moisture in all fertile soils.

Hygroscopic Water is in more intimate relations with the soil particles, and cannot be detected by the senses. Soils that are apparently dry from the escape of capillary water by evaporation, or otherwise, when exposed to a temperature of 212° for some time, lose weight from the loss of hygroscopic water. Capillary water is the chief source of the water absorbed by the roots of plants, but, under otherwise favorable conditions, vigorous plants are able to appropriate hygroscopic water, to some extent, when the capillary water is exhausted.

*How Crops Feed, p. 199.

Behavior of Drainage Water in Soils. As drainage, or hydrostatic, water cannot be used by farm crops, its influence on the soil and growing plants should be carefully studied.

Available Depth of Soils. As only aquatic plants can grow in the retained drainage water of soils, the depth of available soil for the growth of farm crops, in soils that are not shallow from original poverty of constitution, will be determined by the distance of the water table below the surface. If the roots of upland plants penetrate below the level of the water-table, or, if the water table is raised, by rains, to submerge roots already developed, they become unhealthy, and the plants accordingly suffer from defective nutrition, as pointed out in the preceding chapter.

When the rainfall is in excess of evaporation the water table may be near, or even above, the general surface of the soil, as shown by standing puddles of water, and the soil, in this saturated condition, is entirely unfitted for the growth of valuable plants. In time of drouth the water table is lowered, to a greater or less extent, by evaporation, but in the case of heavy or loamy soils this does not immediately restore the reclaimed soil to a favorable condition for growing crops. Heavy and loamy soils that have been saturated with water, and then dried by surface evaporation, have a compact arrangement of their particles, are not readily pulverized, and a considerable time is required to secure the permeable and porous condition that will permit the circulation of capillary water, or a free distribution of the roots of plants, and furnish a favorable environment for the beneficial microbes that are needed to prepare plant food from the inert organic, or other materials, the soil may contain. The atmosphere is likewise excluded from the soil, through its defective porosity, and the supplies of oxygen, that are needed by the plants and absorbed by

their roots, are therefore cut off. Soils that are saturated with drainage water during the spring months, do not respond to the ameliorating influences of tillage, or the application of manures, from their defective physical and biological conditions, and the resulting changes in soil metabolism may involve an actual loss of the elements of fertility. In favorable seasons moderate crops may, perhaps, be grown, but in wet or cold seasons, or when severe drouths prevail, an entire failure of remunerative crops may be expected, and a reasonably high average of productiveness cannot be secured.

Relations of Water to Soil Temperatures. The marked influence of hydrostatic, or drainage, water in lowering the temperature of soils, has often been observed, and it may be well to inquire how this effect is produced, as it will aid us in gaining clearer notions of the relations of soil water to the nutrition and growth of plants. In order to furnish a basis for a rational discussion of the phenomena under consideration, attention must be given to some of the elementary principles of science relating to the various forms, and manifestations of energy.

Conservation of Energy. That the forces of nature appear less mysterious as the progress of knowledge enables us to measure, and trace, their interdependent relations, and refer them to a common law, is strikingly manifest in the recent extended applications of the principle of the conservation of energy, in almost every department of science, and the productive arts. Energy has been defined as "the power of doing work, or of overcoming resistance." It "can neither be created, nor destroyed," but is manifest in a variety of mutually convertible forms, in accordance with what is now recognized as the law of the conservation of energy, which, according to Faraday, is "the highest law in physical science which our faculties permit us to perceive."

This law is formulated by Maxwell as follows: "The total energy of any body, or system of bodies, is a quantity which can neither be increased nor diminished by any mutual action of these bodies, though it may be transformed into any one of the forms of which energy is susceptible." These forms of energy are known as motion, heat, light, electricity, magnetism, chemical affinity, etc., which, in the light of this law, may be looked upon as correlated and convertible terms.

All forms of energy may readily be reduced to heat, and this, therefore, is the standard by which they all are measured. The heat required to raise the temperature of one pound of water one degree, is adopted as the unit of heat, and a unit for measuring work in terms of this heat-unit, is evidently needed in tracing the manifestations of energy in its various transformations.

We are indebted to Joule for the experimental demonstration of the law of conservation of energy, in his experiments to determine the mechanical equivalent of heat, which were carried on from 1840 to 1849, and again, with more exact methods for the purpose of verification, from 1870 to 1877. He proved that the energy expended in raising a weight of one pound 772 feet (or a weight of 772 pounds one foot), was equivalent to the heat required to raise the temperature of one pound of water one degree, i. e., from 60° to 61° F. The unit of work is, therefore, 772 foot-pounds,* the mechanical equivalent of the heat unit.

The conservation of energy was shown by reversing the process. When the weight of one pound falls 772 feet (or a weight of 772 pounds falls one foot), and its motion is arrested, heat is produced that will raise the temperature of one pound of water one degree; that is

*The French unit of heat is the amount required to raise the temperature of one kilogram of water (2.2 lbs.) one centigrade degree in temperature; and its mechanical equivalent is 424 kilogram-meters, or a weight of 424 kilograms raised one meter (3.28) feet.

to say, the heat expended in the work performed in raising the weight, and the heat liberated in its fall, are strictly correlated and equal. The mechanical equivalent of heat (772 foot-pounds) is the unit standard for measuring work, whether it is done by a machine, by animal power, or in the various operations of nature. As the heat unit is equivalent to 772 foot-pounds, the various forms of energy may be measured and expressed in heat-units, representing the energy expended, or, in foot-pounds, representing the work done.

The applications of this law of conservation of energy have led to a revolution in the physical sciences, and they are now recognized as of equal importance in vegetable and animal physiology, which are included in the general term, biology. We can no longer look upon the chemical changes, taking place in the arrangement and rearrangement of the elements entering into the composition of plants and animals, as the sole subjects of interest in their processes of nutrition and growth. More than twenty-five years ago Dr. W. B. Carpenter pointed out to physiologists the importance of distinguishing between "*dynamical* and *material* conditions; the former supplying the *power* which does the work, whilst the latter affords the *instrumental means* through which that power operates," and the early prevailing chemical theories in physiology have gradually given place to broader views, in harmony with the universal law of the conservation of energy.

At the present time the transformations of energy are accepted by physiologists as essential and significant factors in the vital activities and nutritive processes of all living beings. It is now known that the building up of the organic substance of plants and animals (constructive metabolism) involves an expenditure of energy, and that a supply of energy is necessary for the maintenance of life.

The manifestations of energy, in the processes of plant growth, have been observed under conditions that fully demonstrate their significance as factors in vital activities from the mechanical effect produced. President Clark, of the Massachusetts Agricultural College, placed a harness on a squash, so that a lever, to which weights could be attached, resting upon it, gave an equable pressure to the surface, and furnished the means of measuring the mechanical force exerted in its processes of growth. As the squash continued to grow, the weights suspended from the long arm of the lever were increased, until it was found capable of overcoming a resistance of 4,120 pounds.*

In walking several times a day over a well-made asphalt sidewalk last summer, my attention was directed to a gradually increasing elevation of two places in the walk, each less than one foot in diameter, and about two rods distant from a Lombardy Poplar, growing on the adjacent grounds. From day to day the elevation of these circumscribed areas became more marked, in spite of the resisting surface and the tramping they received from pedestrians, until a complete fracture of the asphalt was made, and sprouts from the roots of the tree, which had been pushing their way from below, made their appearance above the surface, and explained the apparent mystery as an incident in the "struggle for existence." The force exerted by the growing tips of these shoots cannot, of course, be expressed in foot-pounds, but if we take into account their small transverse section, and the character of the mass moved, it is evident, from the resistance overcome by them, in proportion to the area of their active surface, that the force exerted must have been enormous.

Energy is not only required and expended in the work of building organic substances, but it is also stored

*Mass. Ag. Rep't, 1874. p. 220.

up as a necessary condition of their constitution, in which form it is called *potential energy.* "A weight requires work to raise it to a height, a spring requires work to bend it, air requires work to compress it, etc.; but a raised weight, a bent spring, compressed air, etc., are stores of energy (i. e., potential energy), which can be made use of at pleasure," and in the same way the stored, or potential, energy of plants must be looked upon as representing the work performed in their processes of construction or growth. "By taking into consideration the amount of organic substance formed by a plant from its first development to its death, it is possible to arrive at some idea of the amount of kinetic (active) energy which the plant has stored up in the potential form; for the heat which is given out by burning the organic substance is but the conversion into kinetic (active) energy of the potential energy stored up in its substance; it is but the reappearance of the kinetic energy which was used in producing the substance. The heat, for instance, which is given out by burning wood or coal, represents the kinetic energy, derived principally from the sun's rays, by which were effected the processes of constructive metabolism, of which the wood or the coal was the product."*

Reference is here made to the active energy used in the strictly constructive processes of the plant, and does not include, as will be seen from what follows, the much larger expenditures of energy involved in incidental processes of plant growth. On the death and decomposition of both plants and animals, the energy that has been used in the constructive processes, and stored up in their tissues as potential energy, is liberated in the form of sensible heat. The heat developed in decaying masses of manure, and other organic materials, arises from the liberated potential energy of the organic substances, of which they are composed.

*Art. Phys. Encyl. Brit., 9th ed., Vol. XIX, p. 56.

The energy required in the constructive processes of plants, as already pointed out, is derived chiefly from the heat and light of the sun, but it is supplemented by the potential energy of organic matters in the soil, which is liberated as heat, through the agency of the soil microbes concerned in their decomposition. In soil metabolism there is, therefore, not only an elaboration of available food for the nutrition of plants, but energy, in the form of heat, is liberated from the soil constituents, which, under favorable conditions, may be again utilized in warming the soil, and in the constructive processes of vegetable nutrition.

It should be remarked, however, that the potential energy of all organic substances came originally from the heat and light of the sun, which must be recognized as the ultimate source of the energy of plants and animals. The energy required in the processes of constructive metabolism in animals, and the energy expended by them in work, is derived from the potential energy of the plants on which they feed, and this supply of energy is quite as essential to their nutrition and well-being, as the constituents of their food that are used in building up their tissues. The obvious significance of this fact in the philosophy of feeding we must pass without further notice.

From what has already been presented in regard to the correlated manifestations of energy, it must be seen that the farmer is constantly dealing with it, not only in the constructive processes of nutrition of plants and animals, but in every interest and detail of farm management, and that the profits of the farm must largely depend upon his skill and success in directing and controlling this prime factor in nature's operations.

Energy of the Universe. The real significance of energy, as a factor in farm economy, cannot, however, be fully appreciated, without taking broader views, that

embrace its relations to all natural phenomena. From the law of conservation, as formulated by Maxwell, it appears that the energy of the universe is a constant quantity, that is neither increased nor diminished by the various changes of form it undergoes, and its terrestrial manifestations must therefore represent but a small part of the stupendous whole.

The ubiquitous and interdependent transformations of energy are tersely stated by Tyndall as follows: "As surely as the force which moves a clock's hands is derived from the arm which winds up the clock, so surely is all terrestrial power drawn from the sun. Leaving out of account the eruptions of volcanoes, and the ebb and flow of the tides, every mechanical action on the earth's surface, every manifestation of power, organic and inorganic, vital and physical, is produced by the sun. His warmth keeps the sea liquid, and the atmosphere a gas, and all the storms which agitate both are blown by the mechanical force of the sun. He lifts the rivers and the glaciers up to the mountains, and thus the cataract and the avalanche shoot with an energy derived immediately from him. Thunder and lightning are also his transmuted strength. Every fire that burns, and every flame that glows, dispenses light and heat which originally belonged to the sun. In these days, unhappily, the news of battle is familiar to us, but every shock, and every charge, is an application, or misapplication, of the mechanical force of the sun. He blows the trumpet, he urges the projectile, he bursts the bomb. And remember, this is not poetry, but rigid mechanical truth. He rears, as I have said, the whole vegetable world, and through it the animal; the lilies of the field are his workmanship, the verdure of the meadow, and the cattle upon a thousand hills. He forms the muscle, he urges the blood, he builds the brain. His fleetness is in the lion's foot, he springs in the panther, he soars in

the eagle, he glides in the snake. He builds the forest, and hews it down, the power which raised the tree, and which wields the axe, being one and the same. The clover sprouts and blossoms, and the scythe of the mower swings, by the operation of the same force. The sun digs the ore from our mines, he rolls the iron, he rivets the plates, he boils the water, he draws the train. He not only grows the cotton, but he spins the fiber and weaves the web. There is not a hammer raised, a wheel turned, or a shuttle thrown, that is not raised, and turned, and thrown by the sun. His energy is poured freely into space, but our world is a halting place, where this energy is conditioned. Here the Proteus works his spells; the selfsame essence takes a million shapes and hues, and finally dissolves into its primitive and almost formless form. The sun comes to us as heat, he quits us as heat, and between his entrance and departure the multiform powers of our globe appear. They are all special forms of solar power—the moulds into which his strength is temporarily poured, in passing from its source through infinitude.

"Presented rightly to the mind, the discoveries and generalizations of modern science constitute a poem more sublime than has ever yet been addressed to the intellect and imagination of man. The natural philosopher of to-day may dwell amid conceptions which beggar those of Milton. So great and grand are they, that in the contemplation of them a certain force of character is requisite to preserve us from bewilderment. Look at the integrated energies of our world—the stored power of our coal-fields; our winds and rivers; our fleets, armies and guns. What are they? They are all generated by a portion of the sun's energy, which does not amount to $\frac{1}{2300000000}$ of the whole. This, in fact, is the entire fraction of the sun's force intercepted by the earth, and, in reality, we convert but a small fraction of

this fraction into mechanical energy. Multiplying all our powers by millions of millions, we do not reach the sun's expenditure. And still, notwithstanding this enormous drain, in the lapse of human history we are unable to detect a diminution of his store. Measured by our largest terrestrial standards, such a reservoir of power is infinite; but it is our privilege to rise above these standards, and to regard the sun himself as a speck in infinite extension, a mere drop in the universal sea. We analyze the space in which he is immersed, and which is the vehicle of his power. We pass to other systems and other suns, each pouring forth energy like our own, but still without infringement of the law, which reveals immutability in the midst of change, which recognizes incessant transference and conversion, but neither gain nor loss. This law generalizes the aphorism of Solomon, that there is nothing new under the sun, by teaching us to detect everywhere, under its infinite variety of appearances, the same primeval force. To nature nothing can be added; from nature nothing can be taken away; the sum of her energies is constant, and the utmost man can do in the pursuit of physical truth, or in the applications of physical knowledge, is to shift the constituents of the never-varying total, and out of one of them to form another. The law of conservation rigidly excludes both creation and annihilation. Waves may change to ripples, and ripples to waves; magnitude may be substituted for number, and number for magnitude; asteroids may aggregate to suns, suns may resolve themselves into flora and fauna, and flora and fauna melt in air, the flux of power is eternally the same. It rolls in music through the ages, and all terrestrial energy—the manifestations of life, as well as the display of phenomena—are but the modulations of its rhythm."*

---

*Heat as a Mode of Motion, N. Y. ed., 1863, pp. 446-449.

CHAPTER III.

Rainfall, Drainage and Evaporation.

The relations of evaporation and drainage to rainfall must now be studied to obtain some of the data required in estimating the expenditures of energy in growing crops. Experiments to determine the amount of drainage and evaporation from soils have repeatedly been made, but a small number of them, however, have been carried on for a sufficient length of time, especially in the United States, to be of assistance in settling general principles. The conditions that may have an influence on evaporation and drainage are so exceedingly complex, that a detailed examination of the available records which have been collated in the following tables, will be required to obtain results of practical value.

As early as 1796 Dr. John Dalton, so well known to chemists as the author of the atomic theory, made a drain-gauge, consisting of a cylinder ten inches in diameter, and three feet deep, filled with soil, with arrangements for measuring the water passing through it. His observations for three years (1796-98) showed that on the average twenty-five per cent. of the rainfall was removed from the soil by drainage, and seventy-five per cent. by evaporation. The last two years, grass was allowed to grow on the soil of the gauge, which must have had an influence on the results.* The average annual rainfall at Manchester, where the experiments were conducted, is about thirty-six inches. This form

*Men. Lit. Phil. Soc. of Manchester, Vol. V, pt. 2, as quoted in J. R. Ag. Soc., 1871, p. 130.

of drain-gauge, known as Dalton's gauge, was adopted by other experimenters, with some modifications of the apparatus, for collecting the drainage water.

Mr. John Dickinson, of Abbots Hill, near King's Langley, Herts, England, made experiments with a Dalton's gauge, the results of which may be profitably studied in detail. His gauge was twelve inches in diameter, and three feet deep, filled with a sandy, gravelly loam, on which grass was growing.* The rainfall was measured with a common rain-gauge. The prominent facts recorded by Mr. Dickinson are given in tables 3, 4, 5 and 6, in convenient form to illustrate the observed variations in drainage and evaporation.

TABLE 3.

AVERAGE RESULTS FOR EACH MONTH FOR EIGHT YEARS WITH DICKINSON'S DRAIN-GAUGE.

Months.	Rain Inches.	Drainage Inches.	Evaporation Inches.	Drainage per c't. of rainfall.	Evapo't'n per c't. of rainfall.
October	2.823	1.400	1.423	49.5	50.5
November	3.837	3.258	0.579	84.9	15.1
December	1.641	1.805	—0.164	100.0+	00.0
January	1.847	1.307	0.540	70.7	29.3
February	1.971	1.547	0.424	78.4	21.6
March	1.617	1.077	0.540	66.6	33.4
April	1.456	0.306	1.150	21.0	79.0
May	1.856	0.108	1.748	5.8	94.2
June	2.213	0.039	2.174	1.7	98.3
July	2.287	0.042	2.245	1.8	98.2
August	2.427	0.036	2.391	1.4	98.6
September	2.639	0.369	2.270	13.9	86.1
Totals and means	26.614	11.294	15.320	42.4	57.6

The heaviest rainfall, it will be seen, was from June to November, and the drainage in the summer half of the year, from April to September, was very small. The average annual rainfall of but 26.6 inches was considerably below the average of the locality for a longer series of years. The comparatively large actual, and percentage of evaporation in the summer months, will likewise be noticed, with the increased drainage in the

*J. R. Ag. Soc., 1844, p. 146.

winter months, notwithstanding the smaller amount of rainfall. These variations must be attributed, in the main, to the higher summer temperature, which would increase the evaporation from the soil, and lead to a more rapid exhalation of water by the grass in its more vigorous growth.

In December, it will be seen, the average drainage exceeded the rainfall for the month, and the evaporation, which is estimated as the difference between drainage and rainfall, falls to zero. Evaporation from the soil undoubtedly occurred, and while the drainage records may be accepted as correct, the estimated evaporation needs an indefinite correction, which will again be noticed in comments on another table. In table 4 the yearly variations in rainfall, drainage and evaporation are given.

TABLE 4.

ANNUAL VARIATIONS IN RAINFALL, DRAINAGE AND EVAPORATION OBSERVED BY DICKINSON.

Years.	Rain Inches.	Drainage Inches.	Evapo'tion Inches.
1836	31.00	17.65	13.35
1837	21.10	6.95	14.15
1838	23.13	8.57	14.56
1839	31.28	14.91	16.37
1840	21.44	8.19	13.25
1841	32.10	14.19	17.91
1842	26.43	11.76	14.67
1843	26.47	8.16	18.31
Means	26.61	11.30	15.32

The annual rainfall varied from 21.10 inches to 32.10 inches, a difference of 11 inches, and in several of the years there was evidently a severe drouth. The annual drainage varied from 6.95 to 17.65 inches, a difference of 10.70 inches. The difference between the rainfall and drainage is accounted for as evaporation, and, on this assumption, the moisture of the soil should be the same at the beginning and the close of the experiments, which may not be the case. This element of error will not, however, materially affect the general averages of the above series of years.

The evaporation would, of course, be influenced by the mean temperature and humidity of the atmosphere, especially in the summer months, and the relative vigor of the growth of the grass on the soil of the gauge, besides other conditions which we need not notice here. The lowest evaporation recorded was 13.25 inches in 1840, with the very low rainfall of 21.44 inches, and 13.35 inches in 1836, with a rainfall of 31.00 inches. The highest amount of evaporation was 18.31 inches in 1843, with a rainfall of but 26.47 inches, which is less than the average of the eight years. If these extremes (which we are unable to explain, in the absence of a record of the peculiarities of these seasons, as to temperature, etc.) are omitted as exceptional, we find that in the remaining five years, with a rainfall ranging from 21.10 to 32.10 inches, the evaporation varied from 14.15 to 17.91 inches, a difference of only 3.76 inches, while the drainage varied from 6.95 to 14.91, a difference of nearly eight inches, from which it appears that the evaporation is less influenced by the rainfall than the drainage.

The averages by months and years do not, however, bring out all of the facts that are required to explain the real relations of rainfall and drainage, and the record is presented in another form in table 5, which will clear up some of the apparently anomalous results which are noticed above.

The remarkable variations in the relations of drainage and rainfall recorded in this table are suggestive. In 1841, the year of highest rainfall, 32.10 inches (or 5.48 inches above the average), there was drainage from the Dalton gauge in but four months of the year, namely, slightly more than half an inch in March, and an unusual amount in the last three months. In the first eight months of the year the rainfall was not quite 1.5 inches above the average for the eight years, and this is

TABLE 5.

RAINFALL AND DRAINAGE FOR EACH MONTH, AND TOTALS FOR EACH YEAR, OBSERVED BY DICKINSON, IN INCHES AND DECIMALS.

Months.	1836 Rain Inches.	1836 Drainage Inches.	1837 Rain Inches.	1837 Drainage Inches.	1838 Rain Inches.	1838 Drainage Inches.	1839 Rain Inches.	1839 Drainage Inches.	1840 Rain Inches.	1840 Drainage Inches.	1841 Rain Inches.	1841 Drainage Inches.	1842 Rain Inches.	1842 Drainage Inches.	1843 Rain Inches.	1843 Drainage Inches.
October	4.55	3.82	1.55	0.02	2.68	0.07	1.68	0.09	1.50	0	4.40	5.99	1.41	0.30	4.82	0.91
November..	3.95	3.14	2.05	0.18	3.55	2.91	4.40	4.70	4.25	2.57	4.28	4.87	5.77	5.00	2.45	2.70
December ..	2.21	1.72	1.70	1.62	1.58	1.84	3.02	3.75	0.40	1.57	2.30	2.80	1.52	0.84	0.40	0.30
January....	2.40	2.32	2.40	2.10	0.31	0.04	1.40	1.04	3.95	3.05	1.50	0	1.36	0.60	1.46	1.25
February ..	2.04	2.04	2.85	2.92	2.65	0.86	1.45	1.51	1.32	1.00	1.02	0	2.02	2.10	2.42	1.95
March	3.65	2.51	0.75	0.01	1.55	2.73	1.92	1.22	0.34	0	1.65	0.53	2.20	1.62	0.88	0
April	2.57	1.74	1.32	0	1.35	0	1.65	0.71	0.34	0	1.85	0	0.47	0	2.10	0
May.........	0.70	0.03	0.94	0	0.84	0	1.22	0.10	2.62	0	1.68	0	1.85	0	5.00	0.74
June........	1.80	0.01	1.86	0	2.85	0	3.31	0.05	1.33	0	3.00	0	2.00	0	1.56	0.25
July	2.29	0.10	1.30	0	2.35	0.09	4.36	0.15	1.18	0	2.80	0	1.93	0	2.09	0
August	2.24	0.15	3.00	0.05	0.95	0	3.65	0.09	1.90	0	3.62	0	1.40	0	2.66	0
September .	2.60	0.07	1.38	0.05	2.47	0.03	3.22	1.50	2.31	0	4.00	0	4.50	1.30	0.63	0
Totals	31.00	17.65	21.10	6.95	23.13	8.57	31.28	14.91	21.44	8.19	32.10	14.19	26.43	11.76	26.47	8.10

accounted for by the unusual rains of June, July and August (in which there was no drainage); while in the last four months it was more than four inches above the average. In the last three months the rainfall was 2.68 inches above the average, and the drainage was 2.68 *inches in excess of the rainfall*, the unusually heavy rain of September (without any drainage in that month), having been partly accounted for as drainage in the following months, and condensation of water from the atmosphere may, to some extent, have taken place.

In the years of next highest rainfall, 31.00 inches in 1836, and 31.28 in 1839, there was drainage every month of the year, while in the remaining six years of the record (including 1841, the year of highest rainfall), drainage was entirely suspended from four to eight months. It will likewise be seen that in four years (1837, '38, '39 and '42) the drainage exceeded the rainfall in February or March, and in five years (1838, '39, '40, '41 and '43) the drainage exceeded the rainfall in one or all of the last three months. In May, 1843, the highest rainfall in a single month (with the exception of November, 1842) was accompanied with a drainage of only 0.74 of an inch, the soil, from its deficiency of moisture during the preceding two months, having evidently absorbed and retained it.

From the percentage columns of table 3, it might be inferred that a regular increase in drainage, and decrease in evaporation, from summer to winter, in both spring and fall, was the rule of general application; but the more detailed record, in table 5, shows that the relations of rainfall to drainage and evaporation are more complex than the figures of averages indicate. The distribution of the rainfall throughout the year, the character of prevailing winds, the temperature and humidity of the atmosphere, the capacity of soils to absorb and retain moisture, and the degree of luxuriance of the

growing crops, are all factors in determining the results, that are readily recognized. As we have not the data for a satisfactory discussion of these causes of variation in the experiments under consideration, we can only notice them and pass on to examine the table of half-yearly averages.

TABLE 6.

HALF-YEARLY AVERAGES, FOR EACH YEAR, AND FOR THE TOTAL PERIOD OF EIGHT YEARS, OBSERVED BY DICKINSON.

Years.	Winter half-year, October to March.			Summer half-year, April to September.		
	Rain Inches.	Drainage Inches.	Evapo'tn Inches.	Rain Inches.	Drainage Inches.	Evapo'tn Inches.
1836	18.80	15.55	3.25	12.20	2.10	10.10
1837	11.30	6.85	4.45	9.80	0.10	9.70
1838	12.32	8.45	3.85	10.81	0.12	10.69
1839	13.87	12.31	1.56	17.41	2.60	14.81
1840	11.76	8.19	3.57	9.68	0.00	9.68
1841	16.84	14.19	2.65	15.26	0.00	15.26
1842	14.28	10.46	3.82	12.15	1.30	10.85
1843	12.43	7.11	5.32	14.04	0.99	13.05
Means ...	13.95	10.39	3.56	12.67	0.90	11.77

In the winter half-year the rainfall varied from 11.30 inches in 1837, to 18.80 inches in 1836, a difference of 7.50 inches, while the drainage was from 6.85 to 15.55 inches, a difference of 8.70 inches, and the range in evaporation was but 3.76 inches, or from 1.56 to 5.32 inches. The average rainfall for the winter half-year was more than for the summer half-year, with about the same range of variation. In the summer half-year there was but little drainage, and in five of the eight years the rainfall and evaporation were both below the average, and it is probable that the evaporation was limited by the deficient supply of water in the soil, and that the water exhaled by the grass, growing on the gauge, was likewise diminished. The average evaporation for the summer half-year is about the same as from a bare soil in the Rothamsted experiments (table 9), and the average rainfall is nearly three inches less. With a full supply of water, the evaporation from the soil and growing crop should have been considerably more than the aver-

age recorded in the table. In the three years of highest rainfall, evaporation was from more than two, to nearly four, inches above the highest amount recorded in the five years of deficient rainfall.

Mr. C. Greaves made drainage experiments, at Lea Bridge, near London, England, for several years, that are of particular interest, as they illustrate the marked difference in soils in retaining water. He had two Dalton gauges, of slate, three feet square, and three feet deep; one was filled with sand, and "the other with a mixture of soft loam, gravel and sand trodden in and turfed." Another tank three feet square and one foot deep was used to measure the evaporation from a water surface. The results of his experiments are given in table 7, copied in a modified form from the Rothamsted paper on "Rain and Drainage Waters."*

TABLE 7.

AVERAGE RESULTS OF EXPERIMENTS IN DRAINAGE AND EVAPORATION FOR FOURTEEN YEARS (1860-73) BY MR. C. GREAVES.

	Rainfall Inches.	Drainage.		Evaporation.		
		Sand Inches.	Turfed Soil Inches.	Sand Inches.	Turfed Soil Inches.	Water Surface Inches.
October	2.730	2.402	0.515	0.328	2.215	1.056
November.....	2.021	1.963	0.833	0.058	1.188	0.707
December.....	2.422	2.173	1.508	0.249	0.914	0.574
January.......	2.870	2.734	2.029	0.136	0.841	0.761
February......	1.596	1.524	1.085	0.072	0.511	0.603
March	1.936	1.605	0.879	0.334	1.060	1.065
Totals, h'lf-yr.	13.575	12.401	6.849	1.177	6.729	4.766
April...........	1.428	1.117	0.275	0.311	1.153	2.098
May	2.056	1.656	0.105	0.400	1.951	2.753
June...........	2.205	1.572	0.156	0.633	2.049	3.142
July...........	1.774	1.212	0.013	0.562	1.761	3.443
August	2.332	1.783	0.113	0.549	2.219	2.850
September....	2.347	1.737	0.071	0.610	2.276	1.606
Totals, h'lf-yr.	12.142	9.077	0.733	3.065	11.409	15.892
Whole year...	25.717	21.478	7.573	4.242	18.138	20.658

The very low water-holding power of the sand is shown in the large proportion of both summer and winter rainfall that appears as drainage water. The summer evaporation from the sand averaged but 3.065

*J. R. Ag. Soc., 1881, p. 325.

inches, while the turfed soil averaged 11.409 inches, or nearly four times as much, and the winter evaporation from the sand averaged but 1.177 inches, against 6.729 inches from the turfed soil, or more than four times as much. With an average annual rainfall of 25.72 inches the sand evaporated, on the average, but 4.242 inches. "The true amount of evaporation is probably, however, greater than this, as it is not very uncommon for the drainage from this gauge to exceed the rainfall, owing, as Mr. Greaves supposes, to condensation of water directly from the atmosphere. This excess of drainage over rain occurs most frequently in January and February.

"On the turfed soil the amount of evaporation from January to March is very similar to that observed on the bare soil at Rothamsted; but from April to September—the growing season of the grass—practically no drainage takes place, nearly the whole of the rainfall being evaporated. Drainage-water was, indeed, collected in July and August only on two, in June on three, and in May and September on four, occasions during the fourteen years. The average amounts evaporated from the turf during summer, winter, and the whole year, namely, 11.409, 6.729 and 18.138 inches, are very similar to those noted at Rothamsted (for ten years, 1870-1880); they are so, however, simply from the very moderate amount of rainfall supplied to the soil. In the wet summer of 1860, 15.608 inches were evaporated by the turf in six months; and in the wet season of 1872, the evaporation during twelve months reached 25.141 inches. There is, thus, but little constancy in the amount of evaporation, which depends largely on the amount of rainfall, and on the activity of vegetation. With a heavier rainfall we should doubtless obtain more constant figures.

"The figures representing the evaporation from a water surface are full of interest. The average summer

evaporation is 15,892 inches; that for the winter 4.766 inches; the total for the year 20.658 inches. The amount of variation is considerable. In 1862 the annual evaporation was only 17.332 inches; in the hot season of 1868 it reached 26,933 inches. There are some obvious reasons why the evaporation from a water surface should be more variable than that from a bare soil. On a water surface, sunshine and wind must always produce their full effect, while on soil, evaporation receives a check as soon as the surface is dried. Another disturbing cause in Mr. Greaves' determinations has been the variable condensations from the atmosphere, making the winter evaporations appear lower than they really are."*

The draining experiments of Mr. Dickinson, already described, were continued by Mr. John Evans, with "two Dalton drain gauges, consisting of cast-iron cylinders three feet in depth and eighteen inches in diameter; one is filled with the surface soil of the neighborhood, the other with fragments of chalk; both bear a growth of grass." These experiments are summarized, in the Rothamsted paper quoted above, as follows: "Mr. Evans' experiments are even more striking examples of the disturbing action of vegetation than those of Mr. Greaves. The average rainfall during fifteen years has been 25.55 inches. Throughout this period the absence of drainage from the turfed soil, during the summer months, has been even more complete than in Mr. Greaves' experiments. The summer drainage from the turfed soil has averaged 0.35 inches, the evaporation 12.12 inches. The winter drainage has been 5.23 inches, the evaporation 7.85 inches. In the whole drainage-year the average drainage has been 5.38 inches, the evaporation 19.97 inches. The summer evaporation, however, actually ranges from 7.59 to 16.09 inches, and that of the whole year from 13.20 to 26.55 inches. This

*J. R. Ag. Soc., 1881, pp. 325, 326.

wide range in the amount of evaporation is, in part, due to the insufficient supply of rain. The full evaporating power of the turf has, perhaps, not yet been shown, the whole of the rainfall having been evaporated, even in the wettest summer of the fifteen years. In these experiments the distribution of the rain has a marked effect on the amount of drainage. Rainfalls not sufficiently heavy to penetrate the turf are probably evaporated, while those passing the turf appear, more or less, as drainage. "In the percolator filled with chalk the average annual drainage has been 8.79 inches, and the evaporation 16.76 inches. In this case the soil would probably be less compact, and the growth of grass less vigorous than in the percolator filled with arable soil; the drainage is, therefore, naturally larger, and the evaporation less."

The Rothamsted experiments relating to drainage and evaporation, which have been carried on under definite conditions since 1870, may be profitably studied, as they furnish the most satisfactory data for tracing the influence of excessive rainfall and severe drouths, on the final disposition of soil water. The drainage experiments have been supplemented with investigations of the moisture retained by soils under different conditions of cropping and rainfall, and the amount of water exhaled by plants in their process of growth.

In 1870 three drain-gauges were made,* each having an area of one-thousandth of an acre (72x87.12 inches), and respectively 20, 40 and 60 inches deep. It was well known that soils that had been disturbed could not be repacked, so that their normal conditions, or relations, to water percolating through them could be secured. This defect of the Dalton gauges was obviated in the construction of the Rothamsted drain-gauges, by building the walls of the gauges of bricks and cement around

*J. R. Ag. Soc., 1881, p. 269.

the mass of soil, without disturbing it, so that the gauges, when completed, were filled with soil in its natural condition. The surface soil, of "somewhat heavy loam," had been cultivated to the depth of eight inches; below this was ten inches of friable clay, followed by a subsoil of rather stiff clay. "The land had previously been under the ordinary arable culture of the farm." The soil of the gauges was "kept bare of vegetation," and represented the conditions of a naked fallow.

TABLE 8.

ROTHAMSTED RAINFALL, DRAINAGE AND EVAPORATION. MONTHLY AND ANNUAL AVERAGES IN INCHES, AND PERCENTAGE OF RAINFALL.

	Rainfall.		Drainage. Mean of 20,40 & 60 in. gauges		Evaporation.	
	Av. of preceding 19 yrs. Sept., 1851 to Aug. 1870.	Averages of eighteen years, Sept., 1870, to Aug., 1888.				
	Inches.	Inches.	Inches.	Per ct. of rainfall.	Inches.	Per ct. of rainfall.
October	3.05	3.33	1.73	51.95	1.60	48.05
November	2.17	3.04	2.16	71.05	0.88	28.95
December	1.88	2.50	1.97	78.80	0.53	21.20
January	2.64	2.58	2.13	82.56	0.45	17.44
February	1.50	2.11	1.54	72.99	0.57	27.01
March	1.67	1.68	0.82	48.81	0.86	51.19
Totals, h'lf-yr.	12.91	15.24	10.35	67.91	4.89	32.09
April	1.76	2.24	0.75	33.48	1.49	66.52
May	2.35	2.16	0.51	23.61	1.65	76.39
June	2.45	2.58	0.66	25.58	1.92	74.42
July	2.51	2.82	0.62	21.99	2.20	78.01
August	2.70	2.46	0.60	24.39	1.86	75.61
September	2.36	2.95	0.90	30.51	2.05	69.49
Totals, h'lf-yr.	14.13	15.21	4.04	26.56	11.17	73.44
Annual	27.04	30.45	14.39	47.26	16.06	52.74
NINETEENTH DRAINAGE, OR HARVEST YEAR, Oct., 1888, to Sept., 1889.						
October	....	1.09	0.06	5.50	1.03	94.50
November	....	4.45	3.44	77.30	1.01	22.70
December	....	1.69	1.55	91.72	0.14	8.28
January	....	1.29	0.90	69.77	0.39	30.25
February	....	1.95	1.63	83.59	0.32	16.41
March	....	1.89	0.83	43.92	1.06	56.08
Totals, h'lf-yr.	....	12.36	8.41	68.04	3.95	31.96
April	....	2.47	0.37	14.98	2.10	85.02
May	....	5.00	3.08	61.60	1.92	38.40
June	....	1.38	0.47	34.06	0.91	65.94
July	....	5.67	2.48	43.74	3.19	56.26
August	....	2.18	0.05	2.29	2.13	97.71
September	....	2.44	0.71	29.10	1.73	70.90
Totals, h'lf-yr.	....	18.84	7.16	38.00	11.68	62.00
Year	....	31.10	15.57	50.06	15.53	49.94

The average results obtained with these gauges for each month for eighteen years, and a separate record for each month of the nineteenth drainage, or harvest year, are given in table 8, together with the totals in half-yearly periods, and the annual averages and percentages.*

A rain-gauge of the same area—one-thousandth of an acre—was likewise made in the vicinity of the Rothamsted drain-gauges.

It will be seen that the average annual and half-yearly rainfall of the eighteen years of the drainage experiments, was considerably above the average of the preceding nineteen years, as recorded in the first column of the upper half of the table, the average annual excess being over three inches. As in the experiments of Mr. Dickinson and Mr. Greaves, the average drainage in the six summer months is very much less than the winter drainage, but these averages do not fully represent the real differences that sometimes occurred. In 1887 there was practically no drainage in the months of July, August and September; and in January, 1881, December, 1884, January and February, 1886, and March, 1888, the drainage was in excess of the rainfall, and in other winter months the drainage was "far above the normal proportion of the rainfall."

The difference between the rainfall and the drainage, in all of the tables, is assumed to represent the evaporation, but it will be seen that, if the preceding period had been very dry, a portion of the rainfall would be retained in the dry soil, and the figures in the column headed evaporation would therefore represent this retained water, and the evaporation proper, or, in other words, the estimated evaporation, would be too high for the particular period. Notwithstanding this element of error, tending to exaggerate the evaporation in a given period, it appears that the estimated evaporation varies but little, as compared with the rainfall and drainage.

* Memoranda of "Field and other Experiments," June, 1890, p. 9.

On the average for eighteen years, the rainfall for the six summer months was 15.21 inches, and the evaporation 11.17 inches. In 1888-9, however, the rainfall of the summer months was 18.84 inches, or 3.63 inches above the average, and the drainage was 7.16 inches, or 3.12 inches above the average, while the evaporation, which must have been favored by the larger supply of water in the soil, was but 11.68 inches, or only half an inch above the average. In the first, or winter half, of the year, the rainfall and drainage were both below the average, and the increased rainfall of the year was evidently owing to the excessive rains of May and July, that were more than twice the usual amount, resulting in 4.43 inches of drainage above the average for the two months, with an increase in the estimated evaporation of only 1.26 inches.

Under the climatic conditions at Rothamsted, with a mean annual temperature of about 48°, and a mean temperature of 61° for July and August, the estimated evaporation from a bare soil, in the six summer months, appears to be quite uniformly between eleven and twelve inches, while the annual evaporation is about sixteen inches. The amount of drainage, therefore, apparently depends, in the main, on the amount of rainfall in excess of this normal demand for evaporation. In table 9 the results for each year and half-year are given, in which the relations of drainage to rainfall will be more fully illustrated. For convenience of reference the years are arranged in order according to the amount of annual rainfall.

The wide range of rainfall from 22.94 inches in 1873-4, to 42.72 inches in 1878-9, with an annual average of 30.63 inches, shows that the period embraced in the table included seasons of extreme drouth and of excessive rainfall. In the winter months the rainfall varied from 7.03 to 21.77 inches, with an average of

TABLE 9.

ROTHAMSTED RAINFALL, DRAINAGE AND EVAPORATION FOR NINETEEN DRAINAGE YEARS, AND FOR EACH HALF-YEAR DURING THE PERIOD, 1870-89, IN INCHES AND DECIMALS. DRAINAGE IS THE MEAN OF THE 20, 40 AND 60 INCH GAUGES.

	Drainage Years, October to September.			Winter half-year, Oct. to March.			Summer half-year, April to Sept.		
Seasons.	Rainfall.	Drainage.	Evapo't'n.	Rainfall.	Drainage.	Evapo't'n.	Rainfall.	Drainage.	Evapo't'n.
1873-74	22.94	4.97	17.97	9.84	3.92	5.92	13.10	1.05	12.05
1886-87	23.61	11.65	11.96	16.02	10.94	5.08	7.59	0.71	6.88
1879-80	24.09	9.81	14.28	7.03	3.95	3.08	17.06	5.86	11.20
1883-84	25.78	11.69	14.07	12.81	8.72	4.09	12.95	2.97	9.98
1871-72	26.31	7.68	18.63	12.17	6.03	6.14	14.15	1.65	12.50
1884-85	26.78	14.65	12.13	14.11	10.00	4.11	12.67	4.65	8.02
1870-71	29.32	9.63	19.69	12.77	5.55	7.22	16.55	4.09	12.46
1888-89	30.09	14.93	15.18	12.36	8.39	3.97	17.73	6.54	11.19
1887-88	30.51	14.75	15.78	11.87	8.87	3.00	18.64	5.88	12.76
1874-75	30.79	12.20	18.59	13.41	7.28	6.13	17.38	4.92	12.46
1885-86	31.02	17.45	13.57	15.56	13.02	2.54	15.46	4.43	11.03
1872-73	31.62	13.77	17.85	19.99	12.85	7.14	11.63	0.92	10.71
1881-82	32.34	15.39	16.95	16.07	10.87	5.20	16.27	4.52	11.75
1877-78	32.59	15.22	17.37	13.92	9.08	4.84	18.67	6.13	12.54
1875-76	34.20	17.08	17.12	19.28	13.19	6.09	14.92	8.90	11.02
1882-83	34.71	20.75	13.96	21.77	17.77	4.00	12.94	2.98	9.96
1876-77	35.79	18.67	17.12	21.36	15.53	5.88	14.43	3.14	11.29
1880-81	36.77	22.15	14.62	19.32	15.69	3.63	17.45	6.46	10.99
1878-79	42.72	25.86	16.86	16.96	13.59	3.37	25.75	12.27	13.48
Means	30.63	14.65	15.98	15.09	10.28	4.81	15 54	4.37	11.17
Per cent. of rainfall		47.83	52.17	....	68.12	31.88	....	28.12	71.88

15.09, and in the summer months the range was from 7.59 to 25.75 inches, with an average of 15.54 inches. The drainage for the year varied from 4.97 to 25.86 inches, with an average of 14.65 inches; the winter drainage varied from 3.92 to 17.77 inches, with an average of 10.28 inches; while the summer drainage ranged from 0.71 to 12.27 inches, with an average of 4.37 inches.

The figures in the table representing evaporation are obviously incorrect in several instances, when the rainfall was below the average. For example, the estimated evaporation of 19.69 inches in 1870-71, is undoubtedly too high, as the drain-gauges were built in 1870, and the blocks of earth would become unusually dry from exposure, by the trenches which were dug around them for the construction of the walls. The difference between the rainfall and drainage, in the first year of the experiment, may therefore be partly accounted for in the water absorbed by the soil to restore its normal amount of moisture, and it could not all be fairly reckoned as evaporation.

Again, the two years in which the annual evaporation is stated to be considerably below the average, viz., 11.96 inches in 1886-87, and 12.13 inches in 1884-85, are years of severe summer drouth, with abnormally low evaporation from deficiency of soil moisture. Neglecting these extremes, as exceptional and readily explained, we find the range of variation in the annual evaporation is from 13.57 to 18.63 inches, a difference of 5.0 inches, while the rainfall varies nearly 20 inches, and the drainage more than 20 inches.

Looking at the summer evaporation as the most important, we find that the summer rainfall was more than an inch below the average in the years 1874, '87, '84, '72, '85, '73 and '83, the evaporation, according to the table, ranging from 6.88 to 12.50 inches. In three of these years the estimated evaporation is probably too high,

from a neglect of soil absorption to supply the deficiency from preceding drouths, while four of the seven years' evaporation was abnormally low from a deficiency of water in the soil during the summer.

In the remaining twelve years of the table the rainfall, averaging 17.53 inches (two inches above the average), varied from 14.43 to 25.75 inches, a difference of 11.32 inches; the drainage varied from 3.14 to 12.27 inches, a difference of 9.13 inches, and the evaporation from 10.99 to 13.48 inches, a difference of only 2.49 inches, while the average summer evaporation for these years is 11.85 inches, or only 0.68 inches above the average for the nineteen years.

This agrees with the conclusions reached in remarks on table 8, that the evaporation from a bare soil is a comparatively constant quantity, while the variations in rainfall are accompanied with corresponding variations in drainage. The annual and half-yearly averages are not materially affected by any corrections we can make for known causes of error.

In the United States there is a wide range of climate, with extended areas in which the rainfall and mean summer temperature is much higher than where these experiments were made, and the results obtained will undoubtedly be modified by the comparatively intense climatic conditions that prevail here.

In the United States census report of 1880 it is stated that the average annual rainfall is from thirty-five to fifty inches, where 62.7 per cent. of the wheat is grown, and that 86.8 per cent. of the corn is grown with an average rainfall of thirty to fifty inches, and 63.4 per cent. where it is from thirty-five to forty-five inches.

As to temperature, more than 87.1 per cent. of the wheat and corn are grown where the mean July temperature is between 70° and 80°, and 38.9 per cent. of the

wheat, and 54.8 per cent. of the corn, are grown where the July mean is between 75° and 80°. The extent to which these conditions of abundant rainfall and high summer temperature influence the relative drainage and evaporation from the soil, has not been definitely determined, but the evidence that has thus far been obtained, seems to show that they are both materially increased.

In Mr. Greaves' experiments (table 7), the evaporation from a water surface averaged 20.66 inches annually for a period of fourteen years. At Whitehaven, in the extreme northwest of England, where the annual rainfall averages 45.25 inches, and there are more cloudy days than in the vicinity of London, the annual evaporation for six years was reported to average 30.03 inches.* In a paper by Hon. George Geddes,† it is stated, on the authority of Dalton, that the annual evaporation from a water surface, in England, is 44.43 inches, but from the results of the experiments of Mr. Greaves, and at Whitehaven, quoted above, this is probably too high.

According to the estimates of Blodget, the annual evaporation from a water surface is twice as active in the United States as in England, but it must vary widely in different localities. It is said to be fifty-six inches at Salem, at Cambridge, and at Boston, Mass., on the authority of several individuals, but whether these statements are based on experiments at the three places, or are estimates from the same data, does not appear. It would be remarkable to obtain the same exact figures in experiments on evaporation, at three places, even in the same vicinity. The average rainfall at Boston is about forty-seven inches.

In the paper by Mr. Geddes, a record of the rainfall and evaporation for each month of the entire year,

* Blodget's Climatology of U. S., p. 227.

† N. Y. Agl. Rept., 1854, p. 159. Farm Drainage, by French, p. 73.

at Ogdensburgh, by Mr. Coffin, in 1838, and at Syracuse, N. Y., by Mr. Conkey, in 1852, is of particular interest, from the close agreement in the evaporation, under wide differences in rainfall. These records are copied in full in table 10, with the months in different order, to show the seasonal variations.

TABLE 10.

RAINFALL AND EVAPORATION FROM A WATER SURFACE, OBSERVED AT OGDENSBURG, AND SYRACUSE, N. Y.

	Ogdensb'g, N. Y., 1838.		Syracuse, N. Y., 1852.	
	Rain Inches.	Evapor't'n Inches.	Rain Inches.	Evapor't'n Inches.
January	2.36	1.652	3.673	0.665
February	0.97	0.817	1.307	1.489
March	1.18	2.067	3.234	2.239
October	2.73	3.948	4.620	3.022
November	2.07	3.659	4.354	1.325
December	1.08	1.146	4.112	1.863
Winter months, or h'lf-yr.	10.39	13.289	21.300	10.603
April	0.40	1.625	3.524	3.421
May	4.81	7.100	4.491	7.369
June	3.57	6.745	3.773	7.600
July	1.88	7.788	2.887	9.079
August	2.55	5.415	2.724	6.854
September	1.01	7.400	2.774	5.334
Summer mo's, or half-yr.	14.22	36.073	20.173	39.597
Totals for the year	24.61	49.362	41.473	50.200

It is remarkable that with a rainfall for the year of 24.61 inches in 1838, at Ogdensburgh, and of 41.47 inches in 1852, at Syracuse, a difference of 16.86 inches, indicating considerable difference in the general character of the two seasons, the evaporation for the year differs but 0.84 of an inch.

In 1838, at Ogdensburgh, evaporation from a water surface was 24.75 inches more than the rainfall, or over twice as much, and January and February were the only months in which it was less than the rainfall; while the summer evaporation was 21.85 inches in excess of the rainfall.

At Syracuse, in 1852, the evaporation for the year was but 8.73 inches above the extraordinary rainfall, while the summer evaporation was 19.42 inches more

than the rainfall. On comparing the colder with the warmer months, we find, in both years, that the winter evaporation is much less, and that it varies more from month to month than in the summer season.

Dr. R. C. Kedzie, of the Michigan Agricultural College, found the evaporation from a water surface, from March 15, to November 15, 1865, was 30.85 inches, the rainfall being 24.35 inches, or 6.5 inches less than the evaporation. These observations on a water surface all seem to indicate that evaporation is more active in this country than in England, and that there is probably, in most localities, a larger amount of water evaporated from soils, than in the drainage experiments we have examined. Quite a number of drain-gauges have been made in this country, but observations have not been conducted for a sufficient length of time to establish any principles relating to drainage and soil evaporation, under our peculiar climatic conditions, and general principles appear to be safer guides than erratic and imperfect experiments.

At the Geneva, New York, experiment station, three drain-gauges, a little more than twenty-five inches square, and three feet deep, were made by inclosing a soil of dark clay loam, and tenacious subsoil, in its natural condition. The natural turf was allowed to remain on one of the gauges; another was kept bare of vegetation; while the third was kept bare, and frequently stirred with a trowel to a depth of one inch, during the

TABLE 11.

DRAINAGE AND EVAPORATION AT GENEVA, N. Y.

Surface condition of soil of gauges.	Drainage.		Evaporation.	
	Inches.	Per c. of rainfall.	Inches.	Per c. of rainfall.
No. 1. Sod	3.46	14.6	20.26	85.4
No. 2. Bare and undisturbed	6.95	29.3	16.77	70.7
No. 3. Bare and cultivated	8.54	36.1	15.15	63.9
Mean of the three gauges	6.33	26.6	17.39	73.4

open season. A detailed report of the observations made with these gauges has not, so far as I know, been published, but the average results for five years (1882-87) are given in table 11, the average annual rainfall for the five years being but 23.72 inches.*

The results here recorded were undoubtedly modified by the exceptional seasons embraced in the period. The annual rainfall at Hobart college, Geneva, one mile and a half from the station, averaged, for twelve years, 29.91 inches, so that the average of 23.72 inches observed at the station must be considered as decidedly below the normal. Two-thirds of the rain, or 15.85 inches, on the average, fell in the summer months, the average for July being 4.15 inches, and for August 3.03 inches, and yet there was, practically, no drainage in either of these months, and but 1.17 inches in the remaining summer months, and in 1887 there was a rainfall of 6.37 inches in July, and 3.03 inches in August, without drainage from the gauge with sod. The mean temperature of April, May, June and July, in 1885, '86 and '87, was above the average for the twelve years observed at Hobart college, and this average is several degrees above the mean of the summer months at Rothamsted, and yet the evaporation at Geneva, from the bare soil, was but 0.79 of an inch for the entire year, and 0.96 of an inch for the summer months, above the average at Rothamsted. In two of the five years, at least, at Geneva, the rainfall of the three warmest months must have been insufficient to supply the water required for the normal amount of evaporation. Taking all of these facts together, it appears probable that the evaporation recorded in the table, representing the difference between the rainfall and drainage, is considerably less than woul appear with a more abundant rainfall.

*6th Ann. N. Y. Exp. St. Rept., 1887, p. 397.

The larger amount of drainage from gauge No. 3, over that from gauge No. 2, may perhaps be attributed, in part, at least, to an absorption of moisture from the atmosphere, by the more porous surface of the soil in gauge No. 3, and it is likewise probable that the evaporation from the soil was not actually less than from gauge No. 2. The influence of the sod, in diminishing the drainage and increasing the apparent evaporation, will also be noticed.*

Summary and Conclusions.

The leading facts and inferences from the experimental evidence, relating to drainage and evaporation, that has been presented, may be summarized as follows: The amount of water evaporated from the soil, in a given case, will depend upon a variety of conditions, the most important of which, in their relations to farm drainage, are the uniform abundance of the soil supply of water, the mean summer temperature and relative

*Since the above was written, the record of these gauges for 1889 has been received. The rainfall for the year was 32.90 inches, or considerably above the average, and the drainage and estimated evaporation was as follows:

Surface condition of soil of gauges.	Drainage.		Evaporation	
	Inches.	Per c. of rainfall.	Inches.	Per c. of rainfall.
No. 1. Sod... ...	12.38	37.63	20.52	62.37
No. 2. Bare and undisturbed.	13.47	41.55	19.43	58.45
No. 3. Bare and cultivated ..	14.40	43.77	18.50	56.23
Mean of the three gauges	13.42	40.79	19.48	59.21

The drainage is decidedly increased, and the evaporation from the bare soil gauges, and the average of the three gauges is more than two inches higher than the five year averages in table 11 The rainfall in June was 7.47 inches, and in July 4.56 inches, or very much above the normal in both cases, which will, in part, account for the increase in drainage. If the unusual rainfall for the year had been evenly distributed, a larger proportion would probably have been disposed of by evaporation.

humidity of the atmosphere, the capacity of the soil to absorb and hold capillary water, and the luxuriance of the growing crop.

Evaporation from a naked, well drained soil will be less than from the same soil, on which crops are growing, and a still larger amount will be taken up from an exposed water surface, or from a water-logged soil, under conditions otherwise the same. In a given locality, where the rainfall is not absolutely deficient, or, approximately stated, does not fall below about thirty inches in the year, the average evaporation from a bare soil remains comparatively constant, while the drainage varies widely with the amount of rainfall.

Under the climatic conditions in England, when the rainfall is not below the average, the results of recorded experiments indicate that the mean annual evaporation from a well-drained bare soil is about sixteen inches; from a soil where crops are growing, at least twenty inches; and from a water surface it may be estimated at about thirty inches.

In the grain-growing area of the United States the mean annual temperature ranges from the mean in England, to over 16° higher; and the mean mid-summer temperature, which is, of course, the most important as a factor in evaporation, is from 5° to 24° higher than in England. From the comparatively high mid-summer temperature of the grain-growing States, it may fairly be assumed that the average evaporation is considerably above that observed in England, and the experiments on the evaporation from a water surface seem to indicate that this increase may amount to nearly, if not quite, fifty per cent.

In the absence of any extended experiments, like those at Rothamsted, we can only make approximate estimates of the annual evaporation, under different conditions, in our comparatively intense climate. From

the evidence that is available it may, however, be safe to estimate the average evaporation from a well-drained bare soil at, at least, twenty inches; from the same soil, with a growing crop of average luxuriance, at about twenty-four inches; and from a water surface, or water-logged soil, at from thirty-five to fifty inches, or more. With a rainfall considerably below thirty inches, the soil evaporation may be somewhat less, from deficiency of soil moisture, but even this must depend, to some extent, upon the distribution of rain throughout the season, and the amount falling in single showers, or within a few hours.

CHAPTER IV.

Energy in Evaporation.

A supply of energy in the form of heat has already been noticed as among the indispensable conditions of plant growth, and we now have to consider its relations to evaporation, and the temperature of soils. The real significance of the manifestations of energy that are ever present in nature's operations, and especially in the quiet, unobtrusive work performed in the growth and nutritive activities of plants and animals, cannot be fully appreciated without making a quantitative estimate of the constructive forces involved in these familiar processes. In order to estimate, with an approximate degree of accuracy, the energy expended in these organic processes, it will be necessary to consider the work performed in several distinct operations, which are, nevertheless, closely correlated in producing the final result.

Evaporation of Soil Water. Water is evaporated from all soils, more or less rapidly, and to a greater

or less extent, and the amount so disposed of will vary widely with soil and atmospheric conditions. As the transformation of water into vapor involves an expenditure of energy, in the form of heat, which, as we have seen, is one of the most important factors in the growth of farm crops, the problem of its control and utilization in profitable production, as far as it can be made available, is one of the most interesting in the applications of science in farm economy.

Energy in Evaporation. The amount of heat used in the work of evaporating soil-water is a matter of practical interest, and it will be convenient to have some simple standard by which it can be approximately measured. As the "heat-units" and "foot-pounds," defined in a preceding chapter, are not familiar standards of measurement to many of our readers, another standard will be used, which, although not as definite, is sufficiently exact for all practical purposes.

In their efforts to secure the strictest economy of fuel in steam engines, engineers have made experiments to determine the available potential energy of coal, and its efficiency in evaporating water under favorable conditions. From the results of experiments in Europe and America, it is stated that one pound of coal will evaporate from 6.73 to 8.66 pounds of water, according to the quality of the coal used. In some published tables one pound of coal is said to evaporate from 7.58 to 9.05 pounds of water, but these figures refer to water at an initial temperature of 212°, and the results are about one-seventh higher than with water at the freezing point.*

In the absence of more definite data we may assume that, under the conditions we have to deal with in agricultural processes, one pound of coal will evaporate 8.5 pounds of water, which is considerably more than is

*Ency. Brit., 9th Ed., Vol. VI, p. 81, IX, p. 809.

realized in ordinary steam engines. With this standard of measurement we will now estimate approximately the energy expended in vaporizing water in the processes of plant growth.

The weight of a cubic foot of water is about 62.4 pounds, which is the British standard, but it will, of course, vary with its temperature and other conditions. The water covering an area of one acre, one inch deep, will therefore weigh about 226,500 pounds, or over 113 tons, and the energy required to evaporate, or change it to vapor, would be represented by more than thirteen tons of coal. This may, however, be expressed in another form, that will be readily understood. We are told that "a good condensing engine, of large size, supplied with good boilers, consumes two pounds of coal per horse power per hour." The energy expended in evaporating 226.500 pounds of water, or one inch in depth on one acre, will therefore represent the work of three horses, day and night, with undiminished powers, for six months.

Energy in Exhalation of Water by Plants. Our standards for measuring energy are applicable alike in estimating the energy expended in the exhalation of water by plants, or in evaporation from the soil, or from a water surface, as the energy required to vaporize the water is the same in all of these processes. The farmer is, nevertheless, interested in the manner in which this circulating capital, in the form of water, is disposed of, as he is directly benefited by the energy expended in the exhalation from his crops, while evaporation from the soil may be indirectly beneficial under favorable conditions, or positively injurious in their absence.

The water exhaled by a good crop of Indian corn we have already estimated at about 960 tons per acre, or the equivalent of 8.5 inches of rainfall. According to the standard we have adopted, this would involve an

expenditure of energy represented by 226,500 pounds of coal, or over 113 tons per acre, and this would represent the work of more than twenty-five horses, day and night, without cessation, for six months.

Energy Expended in Growing Crops. In summing up the results of the drainage and evaporation experiments under discussion in the preceding chapter, the conclusion was reached that in the grain-growing States the exhalation from a crop, and the evaporation from the soil on which it was growing, would amount to twenty-four inches in depth of water in the course of the year, or 2,718 tons per acre, and that a very large proportion of this work was done in the summer months. To vaporize this immense quantity of water involves an expenditure of energy represented by the combustion of 320 tons of coal per acre, or the work of seventy-three horses day and night for six months.

Astonishing as, at the first glance, it may appear, this estimate of the enormous expenditure of energy in the normal processes of growing crops does not, however, represent the whole truth, and there are good reasons for believing that it is considerably too low. In the constructive metabolism of plants, it will be remembered, energy is expended in the direct work of building organic substances, and the amount so used is stored up in the potential form as an essential condition of their constitution, and that it reappears as heat when the plant is burned. A large, but variable, amount of energy must likewise be expended in warming the soil, to provide optimum conditions of temperature for growing crops.

In our estimate of the energy expended in growing a field crop, these demands for energy have been neglected, and attention has been exclusively directed to the work performed in vaporizing the water evaporated from the soil, and exhaled by the leaves of growing plants.

The importance of both of these processes of vaporizing water in the economies of vegetation, and the urgency of the demands for energy to carry them on, should be fully recognized. The water exhaled by the leaves of plants has served its purpose in the transportation of soluble nutritive materials, and must be disposed of, and replaced by fresh supplies taken up by the roots. The activity of the processes of nutrition must, therefore, depend, to a great extent, upon the constant absorption of water by the roots, and its final exhalation by the leaves. In like manner the evaporation of capillary water from the soil itself cannot be looked upon as involving a waste of the supplies of energy, as it is but a phase of a general system of circulation that must be maintained in all productive soils. It serves a useful purpose, in the transportation and distribution of the soluble soil constituents, which are brought from the lower strata towards the surface, where they are most needed by the roots of plants, and it likewise promotes the diffusion of the atmosphere through the porous soil, where its constituents are made available in the processes of soil metabolism and plant nutrition. The capillary water of fertile soils is, in fact, kept constantly in motion, as its equilibrium is disturbed by the drafts made upon it by the roots of growing plants, and evaporation from the surface of the soil, and this last process appears to be one of the essential conditions of fertility.

Energy and Soil Temperatures. We have seen that a certain temperature of the soil must be secured for growing plants, and that, according to the experiments already cited, a minimum of about 48° and an optimum of over 80° is required by our leading farm crops. As the soil is not warmed by the energy expended in evaporation, a supply in excess of this demand is required to raise the temperature of the soil from the freezing point, in our northern climate, to the tempera-

ture that is favorable for plant growth. In growing a crop, under the most favorable conditions of food supply, energy, in the form of heat, as we have already seen, is required and expended, in the work performed in the constructive processes of the plants, in the exhalation of water by their leaves, in evaporation from the surface soil, and in warming the soil, and a failure of the supply for either of these purposes must result in diminished productiveness. To the estimate already made of the energy expended in vaporizing water from soil and plants, must therefore be added the amount required in the constructive processes of nutrition, and in warming the soil, which cannot as readily be formulated, from the lack of experimental data.

Energy and Drainage Water. On the other hand, all water in the soil in excess of what is required in the above-mentioned normal processes, is injurious, and should be removed by drainage. In retentive, undrained soils, this surplus water can only be disposed of by evaporation, and we will try to estimate the probable expenditure of energy involved in this process.

Admitting the approximate correctness of the estimate that the normal beneficial evaporation and exhalation from a well drained soil and a growing crop amounts to twenty-four inches of water annually, it follows that with an annual rainfall of forty inches, which is not unusual in the grain-growing States, there would be sixteen inches of water to be removed from the soil by drainage or evaporation, to secure the best conditions for a growing crop. The energy required to evaporate this mass of water is represented by two hundred and thirteen tons of coal per acre, or the work of forty-eight horses day and night for six months, an immense amount of useless work to be drawn from, or interfere with, the supplies of energy which we have considered essential factors of production. In many localities the average

annual rainfall is more than forty inches, and a larger surplus of water would accordingly need to be removed by drainage, to provide suitable conditions for growing luxuriant crops.

The sun has but little influence in warming soils saturated with water, especially in the spring months, as the available energy is all diverted to the work of evaporating the surplus water, which might be removed by draining. This diversion of energy from useful work, the value of which we have estimated in tons of coal per acre, not only prevents the soil from gaining a proper temperature, but it retards or checks the processes of soil metabolism that are required for the rapid elaboration of plant food.

Besides this practical monopoly of the sun's heat, in evaporating drainage water from the soil, heat is also abstracted from the soil itself, so that evaporation is, in effect, a cooling process. Gisborne says, "the evaporation of one pound of water lowers the temperature of one hundred pounds of soil 10°. That is to say, that if to one hundred pounds of soil, holding all the water which it can by attraction (capillary water), but containing no water of drainage, is added one pound of water, which it has no means of discharging, except by evaporation, it will, by the time that it has so discharged it, be 10° colder than it would have been if it had the power of discharging this one pound by filtration."*

In experiments on a peat bog in Lancashire, England, Mr. Parkes found the thermometer, placed seven inches below the surface, ranged from 12° to 19° higher in the drained, than in the natural bog, for several days in June, and on the mean of thirty-five observations in the course of the month, it was 10° higher in the drained bog. In observations made on various kinds of soil, in the middle of the day, in August, with the thermometer

*Gisborne on Drainage, p. 90.

at from 72½° to 77° in the shade, Schubler found the temperature of dry soils from 13° to 14° higher than the same soils when wet.*

It should be noted, in this connection, that the influence of draining, on the temperature of soils, is exceedingly difficult to determine by direct experiment, on account of the complexity of the conditions involved in the problem. With increased temperature of a drained soil there is, at the same time, an increase in the radiation of heat, and the reading of the thermometer, at a given time, will not represent the real saving of energy in the form of heat that is effected by thorough drainage.

The relations of evaporation to soil temperatures and certain processes of plant growth have thus far been considered as correlated processes, that are carried on in accordance with the law of the conservation of energy, which is now generally accepted as of universal application, and the practical significance of these transformations of energy must be evident from the facts presented.

Capacity of Soils for Heat. Soils differ widely in their capacity to absorb heat of low intensity, and likewise in the facility with which they part with it by radiation. Schubler heated equal bulks of several kinds of earth to a temperature of 144° F., "and observed, in a close room having a temperature of 61°, the time which they respectively required to cool down to 70°."† Their relative capacity for heat was then calculated, taking as a standard calcareous sand at 100. The results may be tabulated, as in table 12.

The greater power of sand for retaining heat will explain, in part, "the dryness and heat of sandy districts in summer." It will be noticed, on comparing tables 12 and 13, that the soils which part with their

---

*J. R. Ag. Soc., 1840, p. 204, How Crops Feed, p. 146.

†J. R. Ag. Soc., 1840, p. 201, How Crops Feed, p. 194.

heat most rapidly when dry, have the greatest capacity for absorbing and holding capillary water, which is probably owing to the greater density or weight of the soils that cool slowly.

TABLE 12.

RELATIVE CAPACITY OF SOILS FOR HEAT, AS DETERMINED BY SCHUBLER.

Kinds of Earth.	Relative power of retaining heat.	Length of time required to cool down from a temperature of 144° to 70°, with a surrounding temperature of 61°.
Calcareous sand	100.0	3 hours 30 minutes.
Siliceous sand	95.6	3 hours 20 minutes.
Sandy clay	76.9	2 hours 41 minutes.
Loamy clay	71.8	2 hours 30 minutes.
Arable soil	70.1	2 hours 27 minutes.
Stiff clay, a brick earth	68.4	2 hours 24 minutes.
Grey pure clay	66.7	2 hours 19 minutes.
Garden mold	64.8	2 hours 16 minutes.
Humus	49.0	1 hour 43 minutes.

In discussing soil temperatures, a distinction must be made between heat of low and of high intensity, as their effects are quite different. The dry soils that cool most rapidly are likewise warmed with greater rapidity when exposed to heat of low intensity, as, for example, the heat radiated to the soil by a warm atmosphere. On the other hand, the sands have a slight advantage in the temperature gained by heat of high intensity, like that from the direct rays of the sun.

As water has a greater capacity for heat than soils, it not only absorbs the heat radiated to the earth, but appropriates it from surrounding objects when changed to vapor. Wet soils are, therefore, nearly alike in their capacity to absorb and retain heat, and, as has already been pointed out, they are not readily warmed.

Radiant Heat and Atmospheric Moisture. Radiant heat is an important factor in the phenomena presented in the immediate environment of growing vegetation, and ordinary thermometers fail to indicate the most significant transformations of energy that take place under the prevailing conditions. A full discussion

of its relations to vegetable nutrition would be out of place here, but attention must be called to some of the known facts in regard to its behavior, that will be of assistance in gaining correct notions of the philosophy of thorough drainage.

Dry air is not readily warmed, and it is therefore said to be transparent to heat. The small percentage of the vapor of water diffused through the atmosphere, more abundant near the earth, and diminishing with the elevation, does, however, readily absorb heat of low intensity, and the air is warmed by this indirect process. The heat of high intensity, on the other hand, which is emitted by the sun, is not intercepted, to any extent, by the diffused aqueous vapor of the atmosphere, but passes on to the earth's surface, where it is either absorbed or expended in the work of evaporation.

The earth, in its turn, radiates heat of low intensity, which is readily absorbed by the vapor of water in the atmosphere, and increases its temperature. And here comes in one of the compensating processes of nature: "The vapor which absorbs heat thus greedily, radiates it copiously," and the radiation of heat of low intensity by the atmospheric envelop of aqueous vapor, furnishes the soil with a supply that is more readily absorbed than that received from the direct rays from the sun.

Between a well-drained, porous soil, and its atmospheric envelop of diffused vapor, there is a constant interchange of energy and moisture, the two factors of paramount importance in the economy of plant life. In regard to the significance of these transformations Professor Tyndall says: "It would be an error to confound clouds of fog, or any visible mist, with the vapor of water; this vapor is a perfectly impalpable gas, diffused, even on the clearest days, throughout the atmosphere. Compared with the great body of the air, the aqueous

vapor it contains is of almost infinitesimal amount, ninety-nine and one-half out of every one hundred parts of the atmosphere being composed of oxygen and nitrogen. In the absence of experiment, we should never think of ascribing to this scant and varying constituent any important influence on terrestrial radiation; and yet its influence is far more potent than that of the great body of the air. To say that, on a day of average humidity in England, the atmospheric vapor exerts one hundred times the action of the air itself, would certainly be an understatement of the fact."*

"The removal, for a single summer night, of the aqueous vapor from the atmosphere which covers England, would be attended by the destruction of every plant which a freezing temperature could kill. In Sahara, where 'the soil is fire and the wind is a flame,' the refrigeration at night is often painful to bear."†

"The power of aqueous vapor seems vast, because that of the air with which it is compared is infinitesimal. Absolutely considered, however, this substance exercises a very potent action. Probably a column of ordinary air ten feet long would intercept from ten to fifteen per cent. of the heat radiated from an obscure source, and I think it certain that the larger of these numbers fails to express the absorption of the terrestrial rays effected within ten feet of the earth's surface. This is of the utmost consequence to the life of the world. Imagine the superficial molecules of the earth trembling with the motion of heat, and imparting it to the surrounding ether; this motion would be carried rapidly away, and lost forever to our planet, if the waves of ether had nothing but the air to contend with in their outward course. But the aqueous vapor takes up the motion of the ethereal waves and becomes thereby

*Tyndall on Radiation, p. 33.

†Heat as a Mode of Motion, p. 405

heated, thus wrapping the earth like a warm garment, and protecting its surface from the deadly chill which it would otherwise sustain."*

This variable and constantly varying envelop of aqueous vapor diffused through the atmosphere, that serves as a blanket to conserve the earth's heat, that would otherwise be lost by radiation, plays an important part in the familiar processes taking place near the earth's surface, and in the less readily observed changes carried on in the upper strata of soils. The phenomena of dew and frost are the result of a thinning of the atmospheric vapor, as in times of drouth, and thus permitting an escape of the radiant heat from the earth's surface, or from objects on it, in clear nights, and the condensation of moisture may extend to the upper layers of the soil.

Another of nature's compensations is here evident. Evaporation, as we have seen, is a cooling process, and, conversely, the condensation of vapor into water is a heating process. The energy expended in evaporating, or vaporizing water, is liberated as heat when the vapor is again transformed into water, in accordance with the law of conservation. The heat radiated from the earth, and causing condensation on the cooled bodies it leaves, is therefore offset, in part, by the heat liberated in the process of condensation, and a check is thus kept on the cooling that would take place from the loss of heat without compensation. The ameliorating influences of draining and tillage on soils are intimately connected with, and largely dependent on, these correlated transfers of energy and moisture, that are brought about by radiant heat through the directing agency of atmospheric vapor.

---

*On Radiation, p. 34.

CHAPTER V.

Advantages of Draining Retentive Soils.

As there are many farms that do not need draining, it may be well to inquire under what conditions it can be profitably practiced. It would certainly be a foolish expenditure of money and labor, to lay drains in land that has a permeable subsoil and allows the free percolation of hydrostatic water, so that the water table is at least four feet below the surface in wet seasons, or after heavy rains. There are extensive tracts of open, porous soils that are not fertile from lack of power to retain capillary water in sufficient quantity to support vegetation, in which irrigation rather than draining is indicated.

Draining can only be recommended when there is a retentive subsoil, which holds the drainage water for a considerable time in the spring and fall months, or after a heavy rainfall in the growing season. It will at once be admitted that swamps and bogs that are saturated with water for several months in the year, and lands overflowed by springs, need draining, but on high lands there are less obvious indications of deficient drainage, which the intelligent observer will not fail to notice.

Indications that High Lands Need Draining. Where water stands on the surface after heavy showers, or is seen in the furrows when plowing in the spring, the soil will, undoubtedly, be improved by draining. Even where water does not show itself at the surface, the dark patches of soil in a recently plowed field, and the growth of mosses, or molds, and aquatic plants, later in the season, show that the water table must be lowered

to provide favorable conditions for the growth of upland plants of greater economic value. The accumulation of water in trial pits, that may be dug to the depth of three or four feet, in wet seasons, is another indication that is quite conclusive.

The indications of deficient drainage are likewise manifest in time of drouth, among which may be mentioned, as the most striking, the appearance of wide cracks in heavy soils that have been saturated with water early in the season, and then dried by evaporation. In such soils there is a lack of porosity, or capillarity; the roots of plants are not well developed, from the absence of suitable conditions for their distribution throughout the soil, and the rolling of the leaves indicates a deficient supply of capillary water for healthy nutrition. After copious showers the plants frequently have a yellowish tinge, from defective assimilation arising from the presence of hydrostatic water in the soil, and at the close of the season the crop matures, or ripens unevenly in the field. Soil metabolism is not active; the conditions do not favor the free circulation of capillary water in the soil, or vigorous root development, and the crop suffers from the check given to its general processes of nutrition. In contrast with these unfavorable conditions for growing crops, we may summarize some of the benefits that may be derived from a judicious system of farm drainage.

Advantages of Draining Retentive Soils. As the surface of the water table is the limit of the healthy root development of farm crops, one of the most obvious effects of draining is to deepen the soil, and thus furnish a wider range for these important agents of nutrition and growth. If the water table is within four feet of the surface of the soil for any considerable time during the growing season, it must materially interfere with the development and distribution of the roots of

most of our farm crops, as, under favorable conditions, they penetrate the soil to greater depths than the limit mentioned, which may be considered the minimum for profitable production.

Schubert made excavations in the field six feet, or more, in depth, and then laid bare the roots of plants by gently washing the soil with a stream of water. He found that rye, beans and garden peas had a dense mat of fine fibrous roots to a depth of four feet from the surface, and wheat roots were traced to the depth of seven feet forty-seven days after sowing, while other crops had roots ranging to the depth of three or four feet.* A greater range of root development has frequently been reported by other observers.

There are numerous indirect advantages of thorough draining which should not be overlooked. On well drained land the rain falling upon the soil, in excess of its capacity for absorption, or the demands of the crop, percolates downwards to the level of the drains, warming the soil in its progress, and increasing its porosity, while the air follows the descending water between the particles of the soil, where its constituents are needed for the nutrition of the plants, and in the processes of soil metabolism. Next to carbon we find oxygen is the most abundant element in the composition of plants. It is freely absorbed by the roots of plants, and "deprived of oxygen the movements of protoplasm, the movements of the roots and of the leaves cease, other manifestations of activity are put a stop to, and the plant dies of suffocation."† Atmospheric nitrogen, also, as we have seen, is appropriated by micro-organisms in the soil, and made available as combined nitrogen for the use of plants. The free admission of the atmosphere between the particles of soils is, therefore, important, and this can only be secured on well drained land.

---

*How Crops Grow, p. 264.

†Plant Life on the Farm, p. 25.

When the hydrostatic water of soils is discharged by drainage, instead of evaporation, there is an immense saving of energy in the form of heat, as has been pointed out in a preceding chapter (p. 63), that may be made available for other purposes, of direct advantage to the growing crops. The enormous amount of heat saved from useless work by drainage would be utilized in warming the soil, and in the metabolic processes that are essential to the healthy, luxuriant growth of crops. Soil metabolism would be promoted, the micro-organisms concerned in the disintegration of organic matters in the soil, and, in the processes of nitrification, would find more favorable conditions for the exercise of their vital activities, plant food would be more rapidly elaborated, and the power of the soil to hold water by capillary attraction in the form best suited for the use of growing plants, would be materially increased. The enhanced porosity of the soil would not only favor beneficial metabolic activities in the soil itself, but, from the improved biological conditions, the roots of plants would be more widely distributed, as they could readily penetrate the soil in all directions, so that its entire mass would be utilized.

Heavy soils, when saturated with water, are injured by working, or by the treading of cattle, as the process of "puddling," as it is technically called, takes place and renders them more retentive and compact. When the water absorbed by such soils is removed by evaporation they become hard and tough, and they do not readily absorb water again, or allow it to percolate through them. In drying they shrink and crack, to the injury of the feeble roots that may have been formed near the surface. They are difficult to work, from their tenacity, and are not easily pulverized, so that thorough tillage, or the preparation of a good seed bed, is made impracticable. These "heavy" soils weigh least.

The sum of the ameliorating effects of draining such soils is to lengthen the season, as they can then be worked earlier in the spring and later in the fall, plants have a longer period of active growth, and a thorough preparation of the soil for seeding can be secured, with economy and increased efficiency in the labor expended.

Among the incidental advantages of draining we should not omit to notice that the surface soil is not washed by heavy rains; and water furrows, that interfere with cultivation and the use of harvesting machinery, may be dispensed with; that crops are not injured by the heaving of the soil by frost; that they are of better quality, and ripen evenly, which is an important consideration in harvesting. It is only on well drained land that manures produce their full effect, either as supplies of plant food, or through their indirect action of increasing soil metabolism.

There are retentive, undrained soils, which yield fair crops in the exceptional seasons, that furnish the most favorable conditions of temperature and distribution of rainfall for their special requirements, while in bad seasons the total failure of the crop, or the decidedly low yield in ordinary seasons, tends to reduce the average below the point of profitable production.

Drainage and Drouths. In localities where the average annual rainfall considerably exceeds the amount required by crops, drouths are liable to occur from an unequal distribution of rain throughout the year, and an absolute deficiency in the growing season. The influence of drainage in promoting the growth of crops in time of drouth should, therefore, receive particular attention.

On well drained land, of fair quality, plants have a vigorous habit of growth that enables them to resist, or overcome, to a certain extent, the injurious influences which, under less favorable conditions, would be mani-

fest from a scanty supply of moisture in the soil. Their widely extended and deep range of root distribution enables them to appropriate the capillary water from all parts of the soil, and when this is exhausted, they may even take up a considerable portion of hygroscopic water, which is less readily parted with by the particles of soil, and which less vigorous and aggressive plants would not be likely to obtain. The soil itself, from its improved porosity, will bring moisture from below by capillary attraction, and will also condense it from the atmosphere, and thus add to the aggregate of the supply. The results of experiments relating to the capacity of soils for absorbing and holding moisture, and the extent to which it may be appropriated by plants will be of interest in this connection.

Amount of Capillary Water in Soils. Schubler made experiments to determine the capacity of soils

TABLE 13.

CAPILLARY AND HYGROSCOPIC WATER RETAINED BY SOILS. SCHUBLER'S EXPERIMENTS.*

Kinds of Earth.	Per cent. of weight.	Per cent. of volume.	Pounds of water in 1 cubic foot of soil.	Tons per acre to depth of 4 feet.	Inches of rainfall.
Silicious sand	25	37.9	27.3	2,370	21
Calcareous sand	29	44.1	31.8	2,770	24
Sandy clay	40	51.4	38.8	3,380	30
Loamy clay	50	57.3	41.4	3,600	31
Stiff, or brick clay	61	62.9	45.4	3,950	35
Pure grey clay	70	66.2	48.3	4,200	37
White pipe clay	87	66.0	47.4	4,120	36
Humus	181	69.8	50.1	4,360	38
Garden mold	89	67.3	48.4	4,210	37
Arable soil	52	57.3	40.8	3,550	31
Slaty marl	34	49.9	35.6	3,100	27
Gypsum powder	27	38.2	27.4	....	....

for retaining capillary and hygroscopic water, by saturating them with water, and then allowing them to drain until the hydrostatic water had been discharged, with results given in the second and third columns of table 13, on which are based the estimates of the last three columns.

*J. R. Ag. Soc., 1840, p. 184.

Before commencing these experiments, the soils were dried at a temperature of 144½°, until they ceased to lose weight, so that hygroscopic, as well as capillary, water, was parted with. The water absorbed was, therefore, hygroscopic, as well as capillary. Experiments like these can, however, give only approximate results, as the same soil, in different degrees of fineness, will vary widely in its capacity to absorb water, the capillarity being increased as the size of the particles diminish.

In 1878, Dr. R. C. Kedzie, of the Michigan Agricultural college,* made an analysis of thirty-one soils, from different localities in Michigan, and tested their capacity to absorb and retain capillary water, by a modification of Schnbler's method. Two-thirds of these soils, including prairie soils and heavy clay loams, had a capacity for absorbing water of from 40.20 to 73.20 per cent., seven of them ranging above 50 per cent.; and one-third of them, among which were samples of the sandy "plain land" in the northern part of the lower peninsula, had a capacity for holding from 29.20 to 39.60 per cent. of capillary water. Allowing for the difference in weight of these soils, one acre to the depth of one foot may be estimated to weigh from three to four million pounds, according to the relative proportion of sand, clay and organic matters they contained. On this basis, the capacity of these soils for retaining capillary water to the depth of four feet would be, for the first group, from 3,000 to 4,000 tons per acre, and for the last group, from 2,300 to 3,100 tons per acre, amounts that are, in most cases, very much in excess of the probable requirements of a crop.

These results, by Schubler's method of determining the capacity of soils to absorb water, even in the modified form adopted by Kedzie, are probably higher than would be obtained with the same soils in their natural

*Mich. Ag Rep't., 1878, p. 386.

condition in the field, and they may be interpreted as representing the maximum capacity of soils for holding water under the best possible physical conditions, that are not likely to be realized, even with well-drained and thoroughly cultivated soils. As indications of the wide margin for possible improvement in the capacity of soils for moisture, by judicious management they are valuable, and they should lead to further investigations relating to the physical properties of soils.

In 1888, Dr. Kedzie made experiments under somewhat different conditions, to determine the capacity of soils to absorb and hold water, which were suggested by the statement that was widely circulated in the agricultural papers, that floods were increased and the effects of drouths intensified by tile draining that in some localities had been quite extensively practiced. These experiments were made with tin tubes two inches in diameter and twenty inches deep, that were weighed in a delicate balance, and then filled with air-dried, sifted garden and other soils, to which water was added until they were saturated with capillary water. Some of the tubes had a tight bottom, to secure the conditions of an undrained soil, and others had a perforated bottom, to secure thorough drainage. By weighing the tubes, under the different conditions of the experiment, the amount of the soil, and the water retained by it, could be readily determined.

He found that, on the average, 36 inches in depth of garden soil retained 12.5 inches in vertical depth of water, which would be equivalent to over 1,415 tons per acre. A fact of still greater importance was likewise demonstrated. When this drained soil was thoroughly saturated with capillary water, "the tubes were left, freely exposed to the air in a room well ventilated, for thirty-three days of hot drying weather." The loss of water by evaporation from the drained soil was nearly

two inches in depth, but, on adding water again to the soil, it was found that its capacity for holding water had increased, as it retained more water than before the period of evaporation, while the undrained soil had a diminished capacity for holding water. It was estimated, from the results of these experiments, that the drained soils had an increased capacity for holding water amounting to about 12.6 per cent.* The evaporation of water from the surface of well drained soils has already been noticed, as serving a useful purpose in various ways, and these experiments seem to indicate that increased capillarity, or power to hold water, must be included in the sum of its ameliorating influences.

Moisture in Cropped and Uncropped Soils. As growing crops exhale large quantities of water in their processes of nutrition, the experimental evidence relating to the influence of this draft of water upon the retained moisture of the soil will be found suggestive. At Rothamsted, experiments have been made to determine the amount of capillary water retained in cropped and uncropped soils under the normal conditions of field cultivation, that are of great practical interest in their bearing on the supplies of water available for crops in time of severe drouths.

In the experiments with wheat grown continuously on the same land, under different conditions of manuring, and with a tile drain through the middle of each plot at a depth of about thirty inches, "the three years of highest produce, both corn (grain) and total produce, were 1854, 1863 and 1864, and all three were seasons of less than the average fall of rain during the four months of active growth. The two seasons of lowest fall of rain during April, May, June and July, were 1868 and 1870; and both gave, with each of the three conditions as to manure, more than the average of corn (grain) over the

*Proc. Soc. for the Pr. of Agr'l Science, 1888, p. 49.

TABLE 14.

YIELD OF WHEAT ON DRAINED LAND, WITH DIFFERENT MANURES, AND AMOUNT OF RAINFALL, IN 1868 AND 1870, WITH AVERAGES FOR NINETEEN YEARS, 1852-1870.

Years.	Dressed grain in bushels of 61 pounds.				Total produce, grain and straw.				Rainfall.				
	Plot without manure.	Barnyard manure pl't.	Mineral manure and ammonia salts, plot 8a.	Mean of the 3 plots.	Plot without manure.	Barnyard manure pl't.	Mineral manure and ammonia salts, plot 8a.	Mean of the 3 plots.	April.	May.	June.	July.	Total.
	bu.	bu.	bu.	bu.	lbs.	lbs.	lbs.	lbs.	in.	in.	in.	in.	in.
1868......	16.63	42.13	44.91	34.56	2,027	6,794	7,477	5,299	2.19	0.73	0.37	0.37	3.66
1870......	15.13	38.00	47.94	33.69	2,002	5,092	6.627	4,574	0.46	1.35	0.98	1.12	3.91
Av.19 yrs	14.25	35.38	37.71	29.14	2,398	6,016	7,088	5,167	1.72	2.36	2.43	2.37	8.88

nineteen years; and in 1868, though not in 1870, there was even more than the average of total produce also, under each of the manured conditions."* With the great deficiency of rain in the growing season, the yield of grain was above, and that of the straw and total produce was below, the average in both years on the unmanured plot. For convenience of reference in discussing the water supply of crops in time of drouth, the yield of wheat for these years, and the averages for nineteen years, are given in table 14, together with the rainfall for the growing months.

"Such were the drouth and heat of May, June and July, 1868, that it is hardly possible to suppose conditions more calculated to induce extreme dryness of soil than those preceding the harvest of that year. Accordingly, toward the end of July, just before the crop was ripe, samples of soil were taken from three plots of the experimental wheat-field, with the special view of determining the amount of moisture retained at different depths. For comparison with these samples, taken at a time of extreme dryness, others were collected from the same plots in January, 1869, after much rain during the preceding ten days; the drains were running, and it was supposed that the ground was quite saturated."† The samples were six inches square, and three inches deep, "down to a total depth of thirty-six inches, or, rather, below the pipe drains." The results of their investigations are given in table 15.

In the July sample of the first three inches from the unmanured plot there was considerably less moisture than in either of the other plots, which may be attributed to more active surface evaporation from the less dense shade of its smaller crop, and the inferior capacity of the soil for holding water. In the next nine inches

*J. R. Ag. Soc., 1871, p. 107.

†J. R. Ag. Soc., 1871, p. 108.

TABLE 15.

PERCENTAGES OF MOISTURE, IN SUMMER AND WINTER, IN THE SOIL AT DIFFERENT DEPTHS, IN THE EXPERIMENTAL WHEAT-FIELD AT ROTHAMSTED, OF PLOTS DIFFERENTLY MANURED.

Samples each 3 inches in depth.	Without manure.			Barnyard manure.			Mineral manures and ammonia salts, plot 8a.		
	July, 1868 Dry.	January 1869 Wet.	Differ'nce.	July, 1868 Dry.	January, 1869 Wet.	Differ'nce.	July, 1868 Dry.	January, 1869 Wet.	Differ'nce.
1	4.05	21.43	17.38	4.48	39.67	35.19	4.31	26.53	22.22
2	7.20	24.54	17.34	7.01	35.62	28.61	6.07	22.93	16.86
3	8.91	24.35	15.44	7.38	28.85	21.47	6.66	20.62	13.96
4	10.65	21.41	10.76	8.14	23.95	15.81	8.45	24.07	15.62
5	11.24	22.07	10.83	9.98	20.59	10.61	12.44	24.84	12.40
6	13.20	21.48	8.28	12.26	21.07	8.81	14.34	24.79	10.45
7	14.03	21.82	7.79	12.51	26.96	14.45	15.20	23.69	8.49
8	15.09	23.59	8.50	12.91	24.87	11.96	16.86	28.98	12.12
9	16.84	24.74	7.90	13.78	25.75	11.97	17.98	27.01	9.03
10	18.03	25.71	7.68	13.45	25.34	11.89	18.53	28.59	10.06
11	14.64	23.97	9.33	14.49	25.18	10.69	17.67	28.93	11.26
12	15.44	22.94	7.50	16.11	22.75	6.64	16.85	27.40	10.55
Mean of 36 inches.	12.44	23.17	10.73	11.04	26.71	15.67	12.95	25.70	12.75

of soil (the average percentage of moisture in samples 2, 3 and 4, from the three plots, being respectively 8.92, 7.51 and 7.06) there is the least moisture in the mineral manure plot, the barnyard manure plot has nearly one-half per cent. more, and the unmanured plot has the highest, as might be expected, from the smaller amount of water exhaled by its small crop. From this point downwards there is a gradual increase in the percentage of moisture in all of the plots. With the exception of the first and last samples of three inches, the barnyard manure plot had decidedly less water at every level than the unmanured plot, and it must have exhaled very much more water in its larger crop, and, therefore, pumped the soil drier than the small crop of the unmanured plot.

When we come to compare the barnyard manure and the mineral manure plots, there is, however, evidence of some other condition than the exhalation of water by the crops that determined the relative amounts of soil moisture in the dry summer. The crop of the mineral manure plot was considerably larger, and therefore exhaled more water than that of the barnyard manure plot, but below the depth of nine inches the samples of the latter, in every case, contained less moisture than the former, that had parted with more water. The only apparent explanation of this difference is the probable better condition of capillarity in the soil of the mineral manure plot which enabled it to bring larger supplies of water from the lower strata of the soil.

In the winter, after heavy rains, we find the unmanured plot had a comparatively limited capacity for holding water. The barnyard manure plot, with its abundant stores of organic matter, contains very much more water in the first nine inches of soil than either of the other plots, but below this the mineral manure plot, at every level (with a single exception), holds consider-

ably more. The barnyard manure plot, on the whole, has the greatest capacity for holding water, especially in the cultivated and manured strata near the surface; while the mineral manure plot was probably less retentive near the surface, and allowed the rain falling on the soil to gravitate more rapidly to the lower strata, and this same condition of porosity may have facilitated the appropriation of moisture from below in the dry season.

In regard to the greater capacity of the barnyard manure plot to retain water, it is remarked by Drs. Lawes and Gilbert, in their paper on the drouth of 1870,* "that while the pipe-drains from every one of the other plots in the experimental wheat-field run *freely*, perhaps, on the average, four or five times annually, the drain from the dunged plot seldom runs at all more than once a year; indeed, it has not, with certainty, been known to run, though closely watched, since about this time last year." The capacity for holding water does not, therefore, seem to depend solely upon the capillarity, but rather upon the combined influence of capillarity and the accumulation of hygroscopic organic substances in the soil. In this latter condition the mineral manure plot seems to have been deficient.

The aggregate differences of the three plots will be best seen when the contained water is estimated in tons per acre. In table 16 the long English tons have been reduced to tons of 2,000 pounds, and the estimated amount of water exhaled by the three crops is given in tons per acre, and their equivalent in inches of rainfall, together with the yield of grain in bushels per acre.

In the third and fourth columns of the table the water exhaled by the crops is estimated on the supposi-

---

*J. R. Ag. Soc., 1871, p. 115.

tion that 85.5 per cent. of the total produce was dry substance, and that three hundred pounds of water was exhaled for each pound of dry substance formed and

TABLE 16.

TONS OF WATER PER ACRE IN THE SOIL OF THREE OF THE EXPERIMENTAL WHEAT-PLOTS AT ROTHAMSTED, IN SUMMER AND WINTER, WITH YIELD, AND ESTIMATED EXHALATION BY THE CROPS.

Plots and manures.	Yield of grain in bu. per acre.	Water exhaled by crop per acre.		Tons of water per acre in soil to depth of 36 inches.		
		Tons.	Inches.	July, '68 in drouth.	Jan., '69, after heavy rains.	Difference.
Unmanured ..	16.62	266	2.30	746	1,564	818
Barnyard manure	42.12	871	7.70	662	1,803	1,141
Min'l manures and am. salts	44.91	959	8.49	777	1,735	958
MANURED PLOTS OVER (or under) UNMANURED PLOT.						
Barnyard manure	25.50	611	5.44	–84	239	323
Min. manure & ammonia salts	28.29	699	6.19	31	171	140

stored in the crop. From this estimate, which must be approximately correct, it appears that the difference in the amount of water in the soil in July and January was sufficient to supply the amount exhaled by the crops of the unmanured and barnyard manure plots, and leave a fair margin for soil evaporation; but in the case of the mineral manure plot the water exhaled by the crop is equal to the difference in the soil water at the two periods of sampling, leaving nothing for soil evaporation, which must have been considerable. The 3.66 inches of rain falling in the course of the four growing months (see table 14), would aid in restoring the balance, but this would, probably, not be equal to the evaporation from the soil itself. Moreover, the indications are that the soil, at the beginning of the growing period, did not contain as much water as when it was sampled in January. If we accept the estimate of Drs. Lawes and Gilbert, that it contained only two-thirds as much, the

supply would be sufficient for the crop of the unmanured plot, while the remaining two plots must have drawn upon supplies by condensation from the atmosphere, and by capillary attraction from the lower strata of the soil, and the amount required by the mineral manure plot must have been quite large.

In the Rothamsted experiments, "a great deficiency of rain," during the period of active growth, was found to be "more adverse to the spring-grown barley than to the winter-sown wheat," and yet more than average crops of grain were grown in seasons of drouth, while the lighter yield of straw would reduce the amount of total produce. In the unusually dry season of 1870, the yield of barley on the barnyard manure plot, where it had been grown continuously for nineteen years, was $52\frac{1}{8}$ bushels of grain, and 4,949 pounds of total produce, while the average for nineteen years was $50\frac{1}{4}$ bushels of grain, and 5,856 pounds of total produce.

In 1870, barley was grown in the field where the drain-gauges were made, as described on page 45 (the first records of which were made in September, see tables 8 and 9). "As the excavations proceeded, barley roots were observed to have extended to a depth of between four and five feet, and the clayey subsoil appeared to be much more disintegrated, and much drier, where the roots had penetrated, than where they had not. Accordingly, it was decided to make careful notes on the sections under the two conditions, and also to take samples of soil and subsoil to a depth below that at which roots were traced, with a view to the determination of the amounts of moisture at the different depths in the two cases. Portions of the barley ground and the fallow ground closely adjoining the drain-gauge plots, but undisturbed by the excavations in connection with them, were selected, and from each, six samples 6x6 inches superficies, by 9 inches deep—that is, in all, to a depth

of 54 inches—were taken," on the 27th and 28th of June.* These were carefully dried and weighed.

The percentage of moisture in the different samples is given in table 17, together with the mean for the entire depth of 54 inches, and the mean of the first 36 inches, for comparison with the wheat soil in table 15.

TABLE 17.

PERCENTAGE OF MOISTURE, AT DIFFERENT DEPTHS, IN CROPPED AND UNCROPPED LAND, AT ROTHAMSTED, JUNE 27 AND 28, 1870.

Depth of Sample.	Fallow land.	Barley land.	Difference.
First 9 inches	20.36	11.91	8.45
Second 9 inches	29.53	19.32	10.21
Third 9 inches	34.84	22.83	12.01
Fourth 9 inches	34.32	25.09	9.23
Fifth 9 inches	31.31	26.98	4.33
Sixth 9 inches	33.55	26.38	7.17
Mean to depth of 54 inches	30.65	22.09	8.56
Mean to depth of 36 inches	29.76	19.79	9.97

For the rainfall of the three preceding months see table 14. "It should be stated that ten days previous to the collection of the samples, about two-thirds of an inch of rain had fallen, and only three days before the collection about one-tenth of an inch; and hence, perhaps, may in part be accounted for the somewhat high percentage of moisture in both soils near the surface at that period of a season which was, upon the whole, one of unusual drouth. Further, for a few days, during the interval since the heavier rainfall, some soil, thrown out from the excavations near, had laid upon the spot whence the samples from the uncropped land were taken, and hence, again, may be accounted for part of the excess near the surface in the uncropped as compared with the cropped land."

There is not only a marked difference in the percentages of moisture in the fallow and the barley land, but in this time of drouth the fallow soil, to the depth of three feet, contained a higher percentage of moisture than either of the wheat-plots, to the same depth, after

*J. R. Ag. Soc., 1871. p. 120.

the heavy rains of January, and the barley soil contained nearly as much as the unmanured wheat plot in January. The significance of these relations will best be seen by estimating the soil moisture in tons per acre and inches of rainfall.

TABLE 18.

TONS PER ACRE OF CAPILLARY WATER IN FALLOW AND BARLEY LAND, AND THEIR EQUIVALENT IN INCHES OF RAINFALL AT ROTHAMSTED, JUNE, 1870.

	Fallow land.		Barley land.		Difference.	
	Tons per acre.	Inches of rainf'l.	Tons per acre.	Inches of rainf'l.	Tons.	Inches.
To depth of 54 inches......	3,220	28.50	2,185	19.34	1,035	9.15
To depth of 36 inches......	2,084	18.44	1,304	11.54	780	6.90

If a liberal allowance is made for the possible check to evaporation from the fallow land, by the soil laying upon it for a few days previous to the time of sampling, to which reference has been made, there is a difference in the two samples of soil of about 1,000 tons of water per acre, to the depth of 54 inches, and over 750 tons, to the depth of 36 inches, which can only be accounted for by the exhalation of water by the crop, as the evaporation from the shaded soil of the barley land must have been decidedly less than from the bare soil of the fallow.

The dry substance of the crop was estimated at "under, rather than over," 4,480 pounds per acre, and the indications are that the crop exhaled more than 300 pounds of water for each pound of dry substance formed by the plants, which would amount to but 672 tons per acre, or considerably less than the observed difference in the water of the two soils to the depth of only 36 inches. It might, however, be assumed that the condensation of water from the atmosphere was more active on the bare soil of the fallow, than on the protected barley soil, when radiation from the soil at night would be intercepted by the shield of vegetation, and the cooling of the soil and consequent condensation would be dimin-

ished. These soils evidently had a greater capacity for storing water than the wheat soils, as will be seen, on comparing the amount of water in the fallow land in time of severe drouth, with that of the experimental wheat plots (table 16), after copious rains in January, and they are nearly equal to the best Michigan soils tested by Kedzie, and the arable soil of Schubler's experiments.

Absorption of Atmospheric Moisture by Soils. Soils are, more or less, hygroscopic, and from this property, moisture, under certain conditions, is absorbed from the atmosphere. There is a dearth of experimental evidence relating to this important property of soils, under conditions that approximate to those which obtain in the field.

Schubler* placed *air-dried soils* under an inverted glass receiver, and over a reservoir of water, the vapor of which was thus brought in contact with the soils. With a mean temperature of 59° to 66°, the soils absorbed the following amounts of water from the atmosphere in twenty-four hours, for each one hundred parts of soil.

TABLE 19.

Kinds of Earth.	Per cent. of water absorbed in 24 hours.
Silicious sand	0
Calcareous sand	0.3
Sandy clay	2.6
Loamy clay	3.0
Stiff clay	3.6
Pure clay	4.2
Humus	9.7
Garden mold	4.5
Arable soil	2.2
Slaty marl	2.9

It may be said that these experiments were made under exceptional conditions, the soil being dry, and the air saturated with the vapor of water, and that they do not furnish indications of what would take place in the field. On the other hand, it must be seen that they

*J. R. Ag. Soc., 1840, p. 195.

were continued but twenty-four hours, and that the soil was dry only at the beginning of the process, while in the field, soils are dried upon the surface in the day time, and cooled at night by radiation, which favors the condensation of atmospheric vapor, and that this process is almost daily repeated during the growing season, so that a much smaller percentage of absorption than was obtained in these experiments, would, in the aggregate, form a considerable item of consequence in the soil supplies of moisture.

The power of soils to absorb moisture from the atmosphere seems to be closely related to their capacity for holding capillary water, as they both evidently depend, to a great extent, upon the hygroscopic properties of organic matters and clay, thus placing the humus and garden mold at the head of the list, closely followed by the heavy clays. The accumulation of root residues in well drained soils, resulting from their greater fertility and wider range of root distribution, will therefore increase their capacity for holding capillary water, and for absorbing atmospheric vapor, as well as the improved physical conditions, to which reference has been made.

In the brief notice of radiant heat, in a preceding chapter, attention was called to the compensations of nature in the reciprocal interchanges of energy and moisture between the soil and the atmosphere that were constantly going on, and in this place a further application of the same principle must be made. As wet soils part with their moisture by evaporation, and dry soils are able to absorb moisture from the atmosphere, there must be frequent exchanges of water, in some form, between the soil and the atmosphere, and the direction in which the transfer is made will depend on their relative humidity and temperature. The capacity of the atmosphere to absorb and retain the vapor of water varies with its temperature. From the high tempera-

ture of a summer day the capacity of the air for moisture is increased, evaporation is rapid, and the surface soil becomes dry. With the lower temperature at night the capacity of the air for moisture is diminished, and the dried soil may then regain a portion of the water it had parted with in the daytime. But this is not all, as the transformations of energy are quite as significant in the alternated processes of evaporation and condensation.

We have seen that evaporation is a cooling process, as heat is abstracted from surrounding objects to perform the work of converting the liquid water into vapor. From the law of the conservation of energy, when this vapor is again changed to the liquid form, the same amount of heat is liberated that was originally required in the work of evaporation, and in the appropriation of the aqueous vapor of the atmosphere, the soil not only obtains water, but it is warmed by the heat that is thus made available. This alternation of the processes of evaporation and condensation must be of immense importance in our intense and variable climate, as it tends to diminish the extremes of temperature in the soil which would otherwise occur. The cooling process of evaporating water from the soil in a hot summer day, prevents an excessive rise of the temperature of the soil, that would be injurious to vegetation, which is so frequently observed in arid regions.

Schubler* found that, with a temperature of 77° in the shade, dark colored dry soils, when exposed to the sun, had a temperature of from 120° to 124°, the sandy soils ranging the highest, which is much above the optimum temperature for growing crops. With a temperature of 80° to 90°, or more, in the shade, the direct heat of the sun would undoubtedly be injurious to crops, when not counteracted by the evaporation of water from the soil, and the capillarity of the soil must be an

*J. R. Ag. Soc., Vol. 1, p. 208. How Crops Feed, p. 196.

important factor in renewing and maintaining the supply. On the other hand, the condensation of the moisture from the atmosphere at night liberates heat, that retards the rapid fall of temperature that would otherwise take place in the soil, in clear nights, from radiation. At certain seasons of the year this is also an important agency in preventing the occurrence of frosts when the temperature of the atmosphere approaches the freezing point, and a clear sky promotes the rapid radiation of heat from the soil. Under such conditions, this conservative influence should be especially manifest in the most productive soils, which have the greatest capacity for water, as they part with heat more rapidly by radiation (see table 12), which would soon lower their temperature to the freezing point, were it not for their greater power to absorb and condense atmospheric vapor and utilize its potential energy, which is liberated in the form of heat.

Hygroscopic Water Used by Plants. By a modification of Schubler's experiment, above mentioned (table 19), Sachs proved that the hygroscopic moisture absorbed by the soil from the atmosphere, may be utilized by plants in their processes of nutrition. A bean plant, growing in a pot of retentive soil, was allowed to remain without watering until the leaves began to wilt. "A high and spacious glass cylinder, having a layer of water at its bottom, was then provided, and the pot containing the wilting plant was supported in it, near its top, while the cylinder was capped by two semicircular plates of glass, which closed snugly about the stem of the bean. The pot of soil and the roots of the plant were thus inclosed in an atmosphere which was constantly saturated, or nearly so, with watery vapor, while the leaves were fully exposed to the free air. It was now to be observed whether the water that exhaled from the leaves could be supplied by the hygroscopic moisture

which the soil should gather from the damp air enveloping it. This proves to be the case. The leaves previously wilted recovered their proper turgidity, and remained fresh during the two months of June and July."*

From other experiments, it was proved that the roots of plants not in contact with the soil, could not absorb moisture from damp air, and we thus have a demonstration "that the clay soil, which condenses vapor in its pores, and holds it as hygroscopic water, yields it again to the plant, and thus becomes the medium through which water is continuously carried from the atmosphere into vegetation." The absorption, or condensation of the diffused vapor of water in the atmosphere by soils, and its utilization by crops, is facilitated by the minute subdivision and porosity of the surface, that can only be secured by thorough drainage and tillage, and when these ameliorating agencies are supplemented by the accumulation of organic matters from the root residues of previous crops, or the application of manures, the atmospheric supplies of water in time of drouths must be of considerable importance.

Air-dried soils may contain from "0.5 to 10 or more per cent." of hygroscopic water, but we do not know what proportion of this may be absorbed by plants, under average conditions, when other sources of supply are exhausted. In the last-mentioned experiment by Sachs the percentage of hygroscopic moisture in the soil probably remained nearly constant, the loss arising from exhalation by the leaves being replaced at once by fresh supplies from the atmosphere. Under less extreme conditions the moisture condensed by soils from the air serves to supplement and conserve the capillary water of the soil that is more readily appropriated by plants, and constitutes, as has already been stated, their chief source

*How Crops Feed, p. 208.

of supply. Sachs made experiments with tobacco plants in three kinds of soil, to determine the extent to which the capillary and hygroscopic water contained in them could be used by plants, with the following results:

TABLE 20.

PERCENTAGE OF SOIL WATER ABSORBED BY TOBACCO PLANTS, IN SACHS' EXPERIMENTS.

Soils.	Percentage of water the soil could hold.	Percentage remaining in the soil when the plants failed to grow.	Difference, or percentage used by the plants.
Black humus and sand..	46.0	12.3	33.7
Loam	52.1	8.0	44.1
Coarse sand.....	20.8	1.5	19.3

From this table it appears that soils not only differ in their capacity to absorb water, which has already been noticed, but they likewise differ widely in the amount they are enabled to retain, or withhold from plants when most needed by them. The sandy soil had the least capacity for moisture, taking up but 20.8 per cent. of its own weight, but it gave up all but 1.5 per cent. for the benefit of the plants. The loam had the greatest capacity for absorbing water, and it withheld but 8.0 per cent. from the plants, while the humus and sand, with less capacity for absorption, refused to give up 12.3 per cent. of its contained water.

It should likewise be remarked that different species of plants present great differences in their power to take up hygroscopic water from a given soil, as shown in their relative ability to withstand the effects of drouth. By draining retentive soils, and the practice of thorough tillage, and the judicious application of manures, these differences in the soils themselves, and in the plants growing on them, are reduced to a minimum, and there is greater uniformity and certainty in the growth of crops of different kinds, especially in seasons of severe drouth.

Drained Soils are Reservoirs for Holding Water. We have seen that crops, in their processes of

growth, require several hundred tons of water per acre, in the course of the season, for their perfect development, and the results of experiments show that retentive soils that are thoroughly drained to the depth of four feet have a capacity for storing water, that is often in excess of the requirements of the crop which they are otherwise fitted to grow. Moreover, this store of capillary water is supplemented by supplies obtained from the subsoil by capillary attraction, and from the diffused vapor of water in the atmosphere by surface condensation. When retentive soils are thoroughly drained, the mass of soil above the level of the drains becomes, in effect, a storage reservoir for retaining capillary water for the use of plants in time of drouth, and if this stored water is not, in itself, sufficient for the requirements of the crop, the improved porosity or capillarity of the soil provides means of increasing it by considerable supplies from other sources.

The advantages of draining, then, are not limited to the removal of the hydrostatic water that interferes with the growth of plants on soils naturally wet, or the discharge of the rainfall that may be in excess of the wants of vegetation; they are alike manifest in preventing injury to crops from the extreme conditions presented in seasons of prevailing drouth and excessive rainfall. Capital expended in draining retentive soils may, therefore, be considered, in part at least, as a permanent insurance investment against losses from unfavorable seasons, and to secure a reasonably uniform and remunerative yield of crops.

Crop Statistics of Good and Bad Seasons. One potent factor in reducing the profits of agriculture, is the low yield of crops obtained in unfavorable seasons, which must be largely attributed to insufficient drainage, in connection with its unavoidable concomitant of imperfect tillage. At the present time there is, in fact, no

problem in practical farm economy of greater importance than that of diminishing the losses that are so frequently caused by adverse climatic conditions, and securing a uniform return for the capital invested and labor expended in crop production.

The statistics of Indian corn, in two of the leading States in its production, in the years 1880 and 1889, compared with the years 1881 and 1887, will be sufficient to illustrate the significance of seasonal variations in crops in determining the average profits of farming. In five years of the preceding decade the average yield per acre was higher than in 1880 or 1889, and these seasons are selected as representing not more than the average yield of good seasons. Between these years was a period of low production, only two years (1885 and 1888), giving an average yield, and the lowest yield was in 1881 and 1887.

The difference in the average yield of corn per acre in 1880 and 1881, was in Iowa, 12.2 bushels; in Illinois, 7.8 bushels; and in the United States, 9 bushels; which represents an aggregate loss in the unfavorable season of 1881, of 81,864,000 bushels in Iowa; 70,953,000 bushels in Illinois; and 578,358,000 bushels in the United States. The difference in average yield of corn per acre in 1887 and 1889, was in Iowa, 14.0 bushels; in Illinois, 13.1 bushels; and in the United States, 6.9 bushels; which represents a loss from the unfavorable season of 1887, of 100,746,000 bushels in Iowa; 96,257,000 in Illinois, and 500,509,000 bushels in the United States. The highest yields per acre in 1880 and 1889, on which the above estimates are based, were 39.5 bushels in Iowa, 32.3 bushels in Illinois, and 27.6 bushels in the United States, or considerably below what is realized by the best farmers in average seasons. When we consider, in connection with this, that all farm crops are subject to the same fluctuations in yield, to which attention has

been called in the case of corn, it must be seen that the influence of unfavorable seasons in diminishing the profits of agriculture are not likely to be overestimated.

Moreover, the effects of bad seasons on undrained retentive soils, resulting from either an excess or deficiency of rainfall are not limited to the low yield of produce for the year, as their impaired physical and biological conditions are not readily corrected and they have a marked influence in diminishing the yield of crops in the most favorable seasons.

CHAPTER VI.

Progress of Discovery and Invention.

The history of agriculture is but a repetition of frequently recurring cycles of empirical methods of practice, which have culminated, from time to time through the teachings of experience, on the same ultimate level, with few indications of real progress aside from what have arisen from the improved implements furnished by the mechanic arts, which have economized labor and made it more efficient. In each age we find the same practical problems presented, which are viewed by farmers from the same standpoint, and, ignoring the lessons of the past, the same means of solving them are suggested by experience, with the result that the familiar methods of former times are repeated and announced as new discoveries, that are evidence of material improvement in the practice of the art.

Even the achievements of science, in its applications to agriculture, in the past half century, have not been sufficient to correct the tendency to a recurrence of these cycles of discovery and apparent progress, from

the attempt on the part of many investigators to solve all problems that may arise, by the results obtained in superficial experiments, made from the standpoint of a single line of investigation, without taking into account the complexity of the phenomena under discussion, and their dependent relations to other departments of science that are quite as significant.

A review of some of the leading facts in the history of land draining will aid us in gaining a rational knowledge of the principles on which the best methods of practice are founded, while it serves to illustrate the cycles of progress in agriculture. The draining of wet lands must have been practiced long before we have any written records of agriculture. There can be no doubt that the first drains were open ditches for removing water from swamps and low grounds that could not otherwise be made to grow useful crops, and water-furrows to discharge surface-water from fields, or to protect them from being overflowed by water from adjacent land. The defects of a system of draining by open ditches were so obvious that covered drains were at once suggested, where they were thought to be admissible, and directions are given for making both open and covered drains, by the earliest writers on agriculture, whose works have been preserved. The construction of embankments as a protection from floods, and the practice of irrigation in time of drouths, had their origin, likewise, in the pre-historic period.

Cato, who wrote in the second century before the Christian era, gave the first specific directions for draining that we are acquainted with, but there is evidence that extensive embankments and irrigation works for the control of water, in the interests of agriculture, were made by the ancient Egyptians and Babylonians many centuries before his time. Cato says, "In the winter it is necessary that the water be let off from the

fields. On a declivity it is necessary to have many drains. When the first of the autumu is rainy there is the greatest danger from water; when it begins to rain the whole of the servants ought to go out with sarcles, and other iron tools, open the drains, turn the water into its channels, and take care of the corn fields, that it flow from them. Wherever the water stagnates amongst the growing corn, or in other parts of the corn fields, or in the ditches, or where there is anything that obstructs its passage, that should be removed, the ditches opened, and the water let away." When treating of the culture of olives, he says, "If the place is wet, it is necessary that the drains be made shelving, three feet broad at the top, *four feet deep*, and one foot and a quarter wide at the bottom. Lay them in the bottom with stones. If there are no stones to be got, lay them with green willow rods, placed contrary ways; if rods cannot be got, tie twigs together." *

In the next century Varro repeats Cato's directions for draining, and Virgil refers to the importance of irrigation in drouths. Columella and Pliny, the best known writers on agriculture in the first century of the Christian era, lay down rules for draining, in which some details are mentioned that were not noticed by the earlier writers. They both recommend open ditches in heavy soils, "but where the ground is more loose, some of them are made open, and others of them are also shut up and covered; so that the gaping mouths of such of them as are blind may empty themselves into those that are open." † They follow Cato in making open ditches, wide at the top and narrow at the bottom, "for such of them whose sides are perpendicular, are presently spoiled with the water, and filled up with the falling down of the ground that lies uppermost." ‡

* Dickson's Husb. of the Ancients, Vol. I, pp. 358, 366.

† Columella "Of Husbandry," Book 2, Chap. 2. Pliny's Nat. Hist., Book 18, Chap. 8.

‡ Columella, l. c.

Pliny, however, makes the additional suggestion that a hedge on the banks of an open ditch will "strengthen it," and "when these drains are made on *a declivity,* they should have a layer of gutter tiles at the bottom, or else house tiles with the face upwards," to prevent washing. These covered drains are trenches half filled with stones or gravel, or "a rope of sprays tied together," and fitted in the bottom, and the whole covered with the earth that had been thrown out. The depth, however, recommended by Columella, is but three feet. That these open and covered drains, from three to four feet deep, were only made in swampy places, or where the soil was saturated with water from springs, is evident from the frequent directions given for making water-furrows, to protect the crops from surface water, particularly in the fall and winter months.*

Columella, however, displays a knowledge of the principles of thorough drainage, when he calls attention to the treatment of the "broad plots of ground," on which the crops fail to grow. "It is proper that marks should be set on these bare spots, that, at a proper time, we may cure diseases of this kind; for when either this ousiness, or any other pest, entirely kills the corn, then we ought to spread pigeons' dung, or, if this cannot be had, cyprus leaves, and then plow them into the ground. *But the principal remedy of all is to make a deep furrow, and thereby drain and convey from thence all moisture; otherwise the aforesaid remedies will be useless and have no effect.*" †

Palladius, in the third or fourth century, repeats the maxims of the earlier writers on draining, and, with Columella, gives three feet as a proper depth for drains. These old Romans were the sole authorities on draining,

* Columella, l. c., Book 2, Chap. 9, Book 11, Chap. 2, etc. Pliny, l. c., Book 18, Chaps. 49 and 64.

† L. c., Book 2, Chap. 9.

and their methods were practiced, without any improvement, for more than a thousand years. A new era in draining literature was begun with the publication of a "broadside," by an anonymous writer in England, in 1583, with the claim, "Herein is taught, even for the capacity of the meanest, how to drain moores, and all other wet grounds or bogges, and lay them dry forever;"* and the appearance in France, in 1600, of the "*Theatre of Agriculture*," by Oliver de Serres, the Lord of Predel, in Languedoc.†

In the last mentioned work, drains four feet deep are recommended, "in order to cut off the source of springs, which is the special aim of this business." The trenches are half filled with stones, and the excavated earth packed above them, making a covered drain "for the commodiousness of tillage." When stones cannot be obtained, an open water-way is secured, by contracting the trench one foot from the bottom, and leaving a shoulder on each side, on which bundles of straw are placed to support the earth with which the trench is filled. This appears to be the only improvement suggested in the construction of drains, since the time of the Romans.

It is evident that deep open, or covered drains were not in common use at this time, as they are only incidentally mentioned in the ponderous folio of over 700 pages, published in London in 1616, called "Maison Rustique, or The Countrey Farme, compyled in the French Tongue," by Stevens and Liebault, and translated into English by Richard Surflet, "with divers large additions out of the works of Serres, his agriculture," etc., "and the Husbandrie of France, Italie and Spaine, reconciled and made to agree with ours here in England, By Gervaise Markham."

* Gisborne Agricultural Drainage, p. 74.

† Klippart's Land Drainage, p. 7. Loudon's Encycl. of Ag'l, p. 1214.

In this elaborate work, covering the entire field of agriculture, as then practiced, including many "secrets" of veterinary practice, the references to draining are brief, and confined, in the main, to directions for throwing land in ridges, and the opening of water-furrows. "Meadow grounds must also be verie well drained from water, if they be subject thereunto, and sluces and draines made either by plough, spade, or other instrument, which may convey it from one sluce to another till it fall into some ditch or river." "Likewise, if there be anie marish or dead water in anie part of your meadow, you must cause the same to runne and drayne out by some Conduits and Trenches; for without all peradventure, the super-aboundance of water doth as much harme as the want scarcitie, or lacke of the same." If the soil "be within any daunger of water, or subject to a spewing and moist qualitie; then you shall lay your lands high, raising up ridges in the middest and furrowes of one side, and according as the moisture is more or lesse, so you shall make the ridges high or low, and the descent greater or lesse; but if your ground, besides the moisture, or by meanes of the too much moisture, be subject to much binding, then you shall make the lands a great deale lesse, laying everie four or five furrowes round like a land, and making a hollowness between them, so that the earth may be light and drie."*

While the knowledge relating to draining, and the prevailing practice of the best farmers at the beginning of the seventeenth century were, in all probability, fairly presented in these books, there is evidence that at about this time, or soon afterwards, important improvements were made in the construction of drains by individuals, which, from the lack of means of communication, were not made public, and of which we have no written records.

* Maison Rustique, pp. 494, 498, 530.

The garden of the monastery of Maubeuge, in France, had been noted for its fertility and the quality and earliness of its fruit. This was finally accounted for by the discovery of a system of pipe drains that had been laid at a depth of four feet "throughout the whole garden," and the indications were that this had been done previous to 1620. The pipes were "about ten inches long and four inches in diameter," one end of which was flaring, or funnel-shaped, and the other made tapering, to fit the expanded end of the adjoining pipe. These pipe-tile drains antedate any others of which we have any knowledge, more than two hundred years, but the history of the invention was lost, and it had no influence on the development of the art of draining.*

In the period from 1645 to 1655, a foundation was laid for an improved agriculture in England, through the influence of Sir Richard Weston, Samuel Hartlib and Capt. Walter Blith. The introduction of clover, and other green crops, including turnips, from "Brabant and Flanders," by Sir Richard Weston (1645), the industry of Hartlib, in collecting and publishing the experience of farmers in new methods, and with new forage crops (1645-55)), and Blith's advocacy of a diversified agriculture, in connection with a system of draining low lands (1649-52), mark this as one of the most important epochs in the history of English agriculture, which we can only notice in its relations to draining.†

"*The English Improver*, or a new System of Husbandry," published by Blith, in London, 1649, was the first work in England in which a system of deep and thorough draining was recommended. A new edition soon appeared, and in 1652 "The Third Impression,

* Klippart, l. c., pp. 9, 12.

† Loudon, Encycl. of Ag'l, p. 46. Donaldson's Ag'l Biography, pp. 21, 25. Copeland, Ag'l An. and Mod., Vol. 1, pp. 101, 107. Blith's Survey of Husb. Surveyed, 1652. Hartlib's Legacy of Husbandry, 1655.

much Augmented, with a Second Part containing Six newer Peeces of Improvement," was published under the imposing title of "*The English Improver Improved*, or the Survey of Husbandry Surveyed, Discovering the Improveableness of all Lands; some to be under a double and Treble, others under a Five or Six Fould. And many under a Tenn fould, yea some under a Twenty fould Improvement. By Wa: Blith, a lover of Ingenuity," which is dedicated in a lengthy epistle, "To the Right Honorable the Lord General Cromwell."

The drains recommended by Blith are essentially the same as those described by the early Roman writers on agriculture. Stones, "green faggots, Willow, Alder, Elm or Thorn," being used to provide a water way in covered drains, and his system is confined to the improvement of low lands. He is, however, entitled to credit for improved implements for cutting trenches, and his earnestness in urging the importance of deep and thorough drainage, in accordance with a definite plan. After urging the necessity of deep drains in boggy ground, he says, "But for these common and many Trenches, ofttimes crooked, too, that men usually make in their Boggy grounds, some one foot, some Two, never having respect to the cause or matter that maketh the Bog, to take that way, I say away with them as a great piece of Folly, lost labor and spoyl; which I desire as well to preserve the Reader from, as to put him upon any profitable experiment; for truly they do far more hurt than good, destroy with their Trench and Earth cast out, half their Land, danger their Cattell, and when the Trench is old it stoppeth more than it taketh away, & when it is new, as to the destroying the Bog it doth just nothing, onley take away a little water which falles from the heavens, and weakens the Bog nothing at all, and to the end it pretends is of no use, for the cause thereof lyeth beneath and under the

bottom of all their workes, and so remaines as fruitfull to the Bog as before, and more secure from reducement than if nothing was done at all upon it." Blith found few followers in his methods of draining, and more than a century elapsed before any improvements in the art were made.

Elkington's System. Joseph Elkington, a Warwickshire farmer, practiced draining for more than thirty years, with considerable success, by a secret process which he claimed to have discovered in 1764. At the request of the Board of Agriculture in 1795, Parliament made a grant of £1,000 to Elkington for his secret. In 1796 Mr. John Johnston was sent out to accompany Mr. Elkington and learn his methods of practice, the results of which were published in 1797.*

Dr. James Anderson, of Aberdeen, Scotland, had, however, published an "Essay on Agriculture and Rural Affairs," in 1775, in which he describes a method of draining by "tapping the springs," which is essentially the same as that practiced by Elkington, and we are informed by Copeland that the same method had been practiced in Italy "from a very ancient date."† This method is only applicable in special cases, where the water of springs is held back by impervious strata, that can be perforated by boring in the bottom of the ditch, so that the water, rising through the auger hole, is discharged by the drain, which may be left open or covered. Elkington adopted the methods of making covered drains, that had been practiced in several counties in England, which consisted in partly filling the trenches with stones, brush or straw, and in some cases channels

---

* "An Account of the most Approved Mode of Draining Land, According to the System Practiced by Mr. Joseph Elkington," Edinburgh, 1797, pp. v-x and 5-6.

† A Practical Treatise on Draining Bogs and Swampy Grounds, by James Anderson, London, 1797, p. 4. Copeland, Ag'l Ancient and Modern, Vol. 1, p. 664.

for water were built with bricks of peculiar form made for the purpose; or horse-shoe tiles, with a broad flange at the bottom, were sometimes used, as shown in fig. 5. Stones were, however, preferred, when they could be readily obtained, as they cost less.

Elkington's system of draining must not be confounded with the method of boring, or digging pits in the bottom of ditches, to discharge water to a lower pervious stratum of soil, which had been practiced many years before. Dr. Nugent, in his travels in Germany, in 1766, described this method of draining marshes that had no available outlet. "A pit is dug in the deepest part of the moor, till they come below the obstructing clay, and meet with such a spongy stratum as, in all appearance, will be sufficient to imbibe the moisture of the marsh above it."* Covered drains are then made, discharging into the pit, which is protected with flat stones and covered with earth.

In the first quarter of the present century tiles of better form than those previously used were brought into notice, but, on the whole, the practice of draining had made but little progress since the time of Cato, as attention was exclusively directed to the draining of swamps and low lands, or the removal of the water of springs from higher lands, and, in most cases, the rude methods of making a water way with stones and brush in covered drains, were essentially the same as described by the Roman writers on agriculture. The better methods which, from time to time, had been adopted by individuals who appeared to be in advance of the age in which they lived, were not widely known, and they, in fact, had been neglected and forgotten. The tile drains in the garden of the Monastery of Maubeuge, already mentioned, are not the only illustration of a lost art in the history of draining. George Stephens, in *The Prac-*

* Elkington's Draining, 1797, p 56.

tical Irrigator and Drainer, published in 1834, says: "In draining the park at Grimsthorpe, Lincolnshire, about three years ago, some drains, made with tiles, were found *eight feet below the surface of the ground;* the tiles were similar to what are now used, and in as good a state of preservation as when first laid, although they must have remained there above one hundred years." Old methods were blindly copied, or, perhaps, in some cases, they were re-invented, as the most obvious expedients for removing water from low lands by means of materials already at hand, but there was no indication of a knowledge of the principles on which the best modern practice is founded.

Deanston System. The time was, however, ripe for the development and general adoption of a better system of draining, even at the beginning of the century. The Board of Agriculture had just completed agricultural surveys of the counties of Great Britain, and increased attention was given to improvements in the practice of agriculture. Among those who were taking an active interest in the progress of agriculture, Mr. Buchanan, a retired manufacturer of Deanston, in Perthshire, Scotland, is entitled to especial notice, for his success in draining the heavy clays on his farm, at Catrine Bank, in the humid climate of Ayrshire, which proved to be the prelude of our present system of draining.

His nephew, James Smith, when gaining a university education, spent his vacations with his uncle on the Ayrshire farm, where he witnessed and became interested in the ameliorating influence of frequent drains (eighteen inches deep) on the retentive clay soils, which, under other management, had been unproductive. "At the early age of eighteen years (1807) Mr. Smith was appointed manager of the Deanston works, that had become the property of a company of which his uncle

was partner."* His energy and successful business methods, and the provisions made for the education and comfort of his "work-people," soon gained for the Deanston Cotton Works the reputation of a model industrial establishment.

In 1823 his early interest in the improvement of clay soils by drainage was revived, and he began to improve the farm of two hundred acres connected with the property, by thorough draining with "parallel drains sixteen to twenty feet apart, and twenty-seven inches deep." In March, 1833, he first published the results of his experience in an article on "*Thorough Draining and Deep Ploughing*," contributed to a local agricultural report, which was favorably received, and "Smith of Deanston" became widely known as the originator of a new departure in farm draining.

In 1836, he gave "a more lucid exposition" of his methods, in another article, "*On Thorough Draining and Deep Ploughing*,"† in which he says: "The principle of the system is *the providing of frequent opportunities for the water rising from below, or falling on the surface, to pass freely and completely off*, and therefore the most appropriate appellation for it seems to be '*The Frequent Drain System*.'" His uncle, Mr. Buchanan, made his drains in Ayrshire eighteen inches deep and twelve feet apart. Mr. Smith's drains, at Deanston, were at first made twenty-seven inches deep and sixteen to twenty feet apart, but in his final paper, giving the results of his more extended experience, he says: "The main should be, at least, three feet, and, if possible, three and one-half or four feet under the surface," and the laterals from ten to forty feet apart, according to the retentiveness of the subsoil.

---

*Donaldson's Ag'l Biog., p. 123.

†Farmers' Magazine, Vol. V, p. 373.

Mr. Smith was the first writer to recommend the thorough draining of high lands, and his reasons for the practice are therefore of interest. After a brief reference to Elkington's system, he says: "The portion of land wetted by water springing from below bears but a very small proportion to that which is in a wet state from the *retention* of the water which falls upon the surface in the state of rain, and a vast extent of the arable land of Scotland and England, *generally esteemed dry, is yet so far injured by the tardy and imperfect escape of the water*, especially in winter and during long periods of wet weather in spring and summer, *that the working of the land is often difficult and precarious, and its fertility much below what would uniformly exist under a state of thorough dryness.* A system of drainage, therefore, generally applicable, and effecting *complete and uniform dryness*, is of the utmost importance to the agricultural interests, and through them, to all the interests of the country. By the system here recommended this is attained, whilst the expense is moderate, and the permanency greater than on any other system yet known." The distinctive features of the Smith of Deanston system may be summed up as follows:

1st. Main drain in bottom of chief hollow at least three feet, or, if possible, three and one-half to four feet deep, with a uniform slope.

2d. Frequent drains ten to forty feet apart.

3d. Drains parallel, at regular distance over the whole field, without reference to the wet or dry appearance of portions of the field.

4th. Drains running directly down the slope.

5th. Stones preferred to tiles on the grounds of cheapness and permanency.

Notwithstanding Mr. Smith's originality and independence, he was apparently biased by the popular prejudice against tiles, on account of the assumed difficulty

of the entrance of water to the drains, and when tiles were used he placed a layer of stones over them, as shown in the following figures, copied from his paper of 1836.

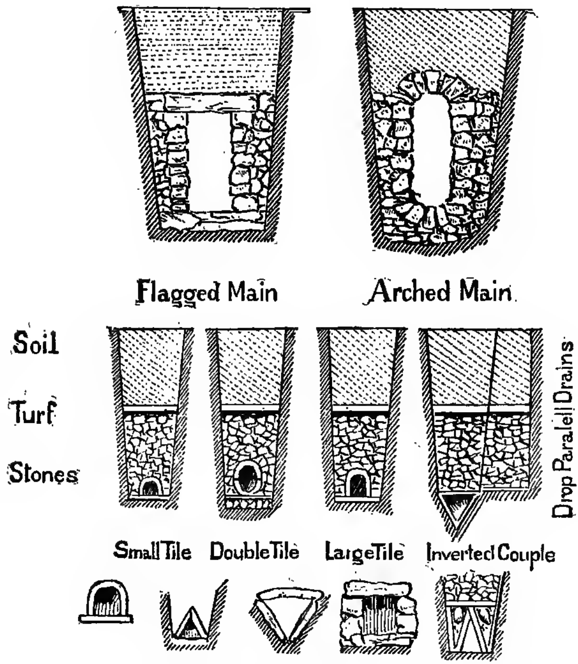


FIG. 4. SECTIONS OF DRAINS, AFTER SMITH OF DEANSTON.

The layer of stones over the tiles do no good, and needlessly increase the expense of draining, and they should not be considered as a characteristic feature of the Deanston system, but rather a conformity to a common practice that had its origin in a misconception of the manner in which water enters drains, which will be discussed in another chapter.

In "*The Practical Irrigator and Drainer*," 1834, by George Stephens, we are told that stones are better than tiles, and where the latter are used they should be covered with, at least, six or eight inches of stones, and, "in any case, however, where tiles are used, the space above them must be filled to the surface of the ground with some porous material, otherwise the drains will be useless, and the undertaking will prove a complete failure." From Mr. Smith's knowledge of general principles, and his sound judgment in other particulars, it is strange that he should have followed the common practice, which was founded in error.

"Smith, of Deanston," was an earnest advocate of the advantages of deep plowing and thorough tillage, in connection with his system of draining, as the title of his papers indicate. He invented a subsoil plow, that was used with the best results, on his farm of two hundred acres, stirring the soil to the depth of sixteen inches. Among the incidental advantages of draining high lands, he made the suggestion that the "absence of ridges and prevalence of a uniform and smooth surface," would facilitate the use of reaping machinery, which he predicted would very soon be employed on every farm.

In the industrial arts, the great discoveries, or inventions, are so often made, at about the same time, by a number of individuals acting independently, that they seem to be the result of the development of the age, rather than the prerogative of individual genius. The progress made in the common stock of intelligence and knowledge, apparently determines the possibilities and direction of the work of discovery and invention. The system of draining invented by Smith, of Deanston, furnishes another illustration of this well-known fact, but it does not, in the least, diminish his well-earned reputation as the exponent of an improved system of

great practical value. Mr. Ph. Pusey, M. P., in 1842, informs us that he had obtained conclusive evidence that a system of draining, essentially the same as th t described by Mr. Smith, had been practiced in Suffolk for more than forty years (some of his correspondents say 100 years), and that for a long time it had likewise been practiced in Essex, "so much so as to be called the Essex system, even in Scotland."* It likewise appears to have been known quite as long in Norfolk and Hertfordshire.

At the beginning of the present century, when Mr. Buchanan was draining the tenacious upland clays of his Ayrshire farm, the farmers of Essex, Suffolk and Norfolk, and other counties of England, were using the same means of ameliorating retentive soils, but they had no Smith of Deanston to formulate their improved methods as a system of general application, and they were soon neglected, and finally only known through tradition, or the exposure of their work in subsequent excavations, under conditions that indicated the time of its performance. These improved methods, like the tiles in the garden of the monastery of Maubeuge, and in the park in Lincolnshire, which we have noticed, were forgotten, as there was no written record of their history, and the time had not come for a general appreciation of their value as a means of agricultural improvement. The history of agriculture abounds in illustrations of the re-discovery of old methods that are dressed up and announced as representing the latest development of the art, without any marked advance in the fundamental principles of a correct practice.

In 1842, the interest taken by farmers in the subject of draining, as the Smith of Deanston system became better known, led the Royal Agricultural Society to offer a prize of "Fifty Sovereigns, or a piece of Plate

*J. R. Ag. Soc., 1842, Vol. III, p. 170. 1843, Vol. IV, pp. 23-49.

of that value," for an essay on "the best mode of Under Draining Land."* The prize was awarded to Thomas Arkell, a Wiltshire farmer, in the following year, but the essay contained nothing of permanent value, as his methods of draining were the results of his own personal experience, uninfluenced by what had already been done by others, and the discussion of principles did not fairly represent the best practice of the time.

Deanston System Improved. Mr. Josiah Parkes, consulting engineer of the Royal Agricultural Society, was the first to suggest any improvement on the Smith of Deanston system. In 1843 he made a "Report on Drain Tiles and Drainage," the society having offered a "premium of ten sovereigns for the drain tile which should fulfill certain specified conditions," in which he describes the different forms of tiles exhibited.† He urges the advantages of pipe-tiles, which, he says, were first made thirty-five years before in Kent, "by bending a sheet of clay, as usually prepared for the common drain-tile, over a wooden cylindric mandrel. In consequence of the imperfect union of the two faces of the clay, a narrow slit was left throughout the length of the tile, which served, and was then thought necessary, to admit the water." The pipe-tiles exhibited were from one inch to two and one-fourth inches in diameter, and the sole tiles from one and one-half to two and three-fourths inches, and Mr. Parkes cites the experience of several farmers to show that the small pipes of one inch had a sufficient capacity for thoroughly draining the land.

In remarks on the use of these small pipes, he says: "the principle that *less frequent but very deep drains are equally effective with more numerous and shallower ones,* is recognized by these intelligent and practical farmers. It must also be considered as a discovery of

---

*J. R. Ag. Soc., 1843, p. 319.

†J. R. Ag. Soc., 1843, p. 369.

no slight national importance, that experience has proved a very much smaller area of drain to suffice for passing the water filtrating through an acre of land, than has hitherto been imagined; for it is mainly owing to the substantiation of this fact, that the pipe-tile of the eastern counties, and Mr. Etheredge's small tiles and covers (horse-shoe tiles with a sole) can be supplied with such a remarkable economy, in comparison with the old tile, and with most other materials hitherto employed in drainage."

Another decided improvement brought out by Mr. Parkes, was in the method of covering the tiles. Former writers, as we have seen, insisted that a covering of stones or other porous material was necessary when tiles were used. The fallacy of this assumption is shown, by Mr. Parkes, in the experience of Mr. John Taylor, of Kent, who used tiles one and one-half inches in diameter. He says, "I have my drains dug from three feet six inches to four feet deep; *the bottom of the drain is left for the pipe to quite fill it, so that it is impossible for the pipe to move after it is put into the drain. Clay is then well rammed over the pipes to two feet in depth,* which I prefer to anything else when it can be got to cover the tiles." Mr. Taylor, who was a tenant farmer, then remarks, "I have thoroughly drained forty acres, and have many other fields partly drained. I should be glad to drain the whole farm, which contains about three hundred acres, provided my landlady would find tiles; or I would gladly pay five per cent. upon the outlay, but I am sorry to say, she discontinues to support that first step of improvement, *land-draining,*"*

In 1844, in a letter to "Ph. Pusey, Esq., M. P." "1. On the Influence of Water on the Temperature of Soils. 2. On the Quantity of Rain-water and its Discharge by Drains," Mr. Parkes made a valuable contri-

*J. R. Ag. Soc., 1843, p. 378.

bution, to our knowledge, of the principles of draining, and pointed out improvements on the Smith of Deanston system that led to the development of the best modern practice. He made a judicious and consistent application of the known facts of science at the time, and gave the results of his own experiments on the temperature of drained and undrained soils, in connection with the experiments of Mr. Dickinson, on the relations of rainfall to drainage and evaporation, which we have quoted in a preceding chapter. He recommends the use of small pipes for laterals, and "parallel drains considerably deeper and less frequent than those commonly advocated by professed drainers, or in general use." After a review of the actual and relative cost and efficiency of drains that had been made at different distances and depths in retentive soils, he sums up the results in the following table:

TABLE 21.

MASS OF SOIL DRAINED AND COST OF DRAINING FOR DIFFERENT DEPTHS AND DISTANCES OF TILES.

Depth of drains in feet.	Distance between the drains in feet.	Mass of soil drained per acre in cubic yards.	Mass of soil drained for 1*d* in cubic yards.	Surface of soil drained for 1*d* in square yds.
2	24	3226½	4.10	6.27
3	33⅓	4840	8.93	8.93
4	50	6453	12.00	8.96

This table represents the results of the experience of Mr. Thomas Hammond, of Kent, who made many experiments in draining, to which Mr. Parkes frequently refers in his papers. An experiment made on the influence of depth on the discharge from tile drains was reported as follows: With reference to "the quantity of water discharged from different drains, after rain, in the same time," Mr. Parkes says: "I have only succeeded in obtaining sufficiently exact information from Mr. Hammond, whose intelligence had led him to make the experiment without any suggestion from me.

He states, 'I found, after the late rains (Feb. 17, 1844), that a drain four feet deep ran eight pints of water in the same time that another three feet deep ran five pints, although placed at equal distances.' The circumstances under which this experiment was made, as well as its indications, deserve particular notice. The site was the hop-ground before referred to, which had been underdrained thirty-five years since to a depth varying from twenty-four to thirty inches, and though the drains were laid somewhat irregularly and imperfectly, they had been maintained in good action. Mr. Hammond, however, suspecting injury to be still done to the plants and the soil by *bottom water*, which he knew to stagnate below the old drains, again underdrained the piece in 1842 *with inch pipes*, in part to three feet, and in part to four feet in depth, the effect proving very beneficial. The old drains were left undisturbed, but thenceforth ceased running, the whole of the water passing below them to the new drains, as was to be expected. The distance between the new drains is twenty-six feet, their length one hundred and fifty yards, the fall identical, the soil clay. The experiment was made on two drains adjoining each other, i. e., on the last of the series of the three feet, and the first of the series of the four feet drains. The sum of the flow from these two drains, at the time of the trial, was nine hundred and seventy-five pounds per hour, or at the rate of nineteen and one-half tons per acre in twenty-four hours; the proportionate discharge, therefore, was twelve tons by the four-feet, and seven and one-half tons by the three-feet, drain. No springs affected the results."*

The system of draining recommended by Mr. Parkes differs from that of Smith of Deanston, in the greater distance between the drains, and the greater

*J. R. Ag. Soc., 1844, p. 154. The discharge is given in long tons of 2,240 pounds.

uniform depth, with the exclusive use of pipe tiles (one inch in diameter for laterals), covered directly with the earth thrown from the ditch.

In 1846 Mr. Parkes presented further details in regard to his system of draining, in a lecture before the Royal Agricultural Society, in which he says, in regard to his own practice at that time: "drains are being executed at depths of from four to six feet, according to soil and outfall, and at distances varying from twenty to sixty-six feet; complete efficiency being the end studied, and the proof of such efficiency being that, after a due period given for bringing about drainage action in soils unused to it, the water should not stand higher, or much higher, in a hole dug in the middle between a pair of drains, than the level of those drains."*

He gives a number of examples illustrating the advantages of deep draining, discusses the causes of obstruction in drains, including deposits of oxide of iron, and claims that pipe tiles should alone be used, on the score of economy, efficiency and durability. Since that time but little has been added to our knowledge of principles, or methods of construction, by the numerous books on draining that have been published.

Mr. John Johnston, of Geneva, N. Y., is entitled to the credit of making the first practical demonstration, in this country, of the advantages of thorough draining. In 1835 he imported sample tiles (of the horseshoe form) from Scotland, and began making them for his own use by hand, as all draining tiles were then made. In 1838 handmade tiles were manufactured at Waterford, N. Y., and sold for twenty-four dollars per thousand.

Evolution of Drain Tiles.

A brief description of the various forms of tiles that have been used in draining, and the reasons that have

*J. R. Ag. Soc., 1846, p. 256.

led to a succession of modified forms, and the final adoption of the round, or pipe-tile, as the only satisfactory one, will serve to illustrate some of the principles involved in the construction of permanent and efficient drains.

From the house, or roofing tiles, used by the ancients, to prevent the washing of the earth in the bottom of drains, to the horseshoe form, made by bending a sheet of clay over a rounded surface, the transition is quite natural. The horseshoe form was, in fact, the original type of draining tile which came into common use, and it was the only form practically known in England and the United States for several years. The change from the roofing tiles, which only served the purpose of protection from washing, to the horseshoe tile, which furnished an open channel for the water, was not, however, made at once. Bricks of a peculiar form, for building a water way, or hollowed out on one side, to provide a channel for the water, were used in many localities, particularly for the larger drains, before the invention or general introduction of horseshoe tiles, that now appear

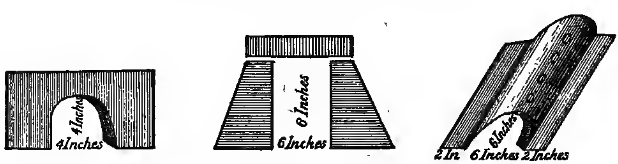


FIG. 5. DRAINING BRICKS AND TILE, LATTER PART OF THE LAST CENTURY.

to be the simplest device for the purpose. In the time of Elkington, bricks and tiles of the forms shown in fig. 5 were used, to a limited extent, but they were too expensive for farm drainage. When the bottom of the ditch was firm they were used as represented in the figure, but in soft ground, the right and left hand forms

were inverted, and another placed on top of them, to form a closed channel.

The cheaper and simpler horseshoe tile, fig. 6, soon superseded these crude and clumsy devices for conducting drainage water. The defects of the popular horseshoe tile were numerous, and various plans for correcting them were tried. When there was but little fall in the course of the drain, obstructions were of common occurrence from the rising of the soft earth in the bottom of the drain, from the hydrostatic pressure of the soil water, until the tiles were completely filled with earth, or, when the fall was considerable, the tiles were undermined by the current of water, and displaced.

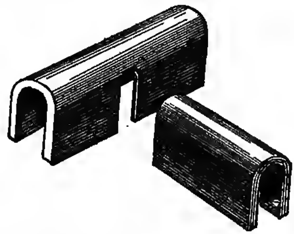
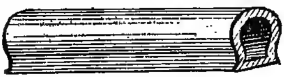


FIG. 6. HORSESHOE TILES, SHOWING MANNER OF FORMING JUNCTIONS.

From the mistaken notion that the tiles settled into the bottom of the drain, from the pressure above them, and thus became filled with earth, the lower edges of the sides of the tile were made thicker, forming a broad foot for the tiles to rest on. This was a common form of the horseshoe tile in this country, but it did not prevent the drains from filling with earth, and it could not, of course, remedy any other of the defects of this form of tile. In England, the two most obvious defects of this form of tiles were both corrected by flat sheets of burned clay, or soles, as they were popularly called, laid, as represented in fig. 7, and "tiles and soles," or "tiles and covers," were quite generally adopted. As the expense and inconven-

FIG. 7. HORSESHOE TILES AND SOLES, AFTER HENRY STEPHENS, 1848.

ience in handling and laying were increased by making the tiles in two pieces, the next step in the evolution of tiles was naturally suggested, and the sole was made a part of the tile itself, as represeuted in figs. 8 and 9, called "horseshoe pipe tiles" in England, and D, or "flat-soled tiles," in the United States.



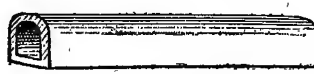


FIG. 8. HORSESHOE PIPE TILE, AFTER HENRY STEPHENS, 1848. FIG. 9. FLAT-BOTTOMED PIPE TILE AFTER FRENCH, 1859.

This form of tiles was claimed to be a decided improvement on the horseshoe tiles, with a separate sole, but it had inherent defects that more than offset its assumed advantages. In the process of burning, the curved, or upper side of the tiles, was found to shrink more than the flat, or under side, and when they were laid on a true grade there were, more or less, wide open spaces at the top of the joint between two tiles, when their soles were in contact. Silt was readily admitted to the drain through these open joints, and its accumulation on the broad and flat bottom of the tiles was a frequent cause of obstruction. In the old form of tiles, with separate soles, the joints between the tiles were not as open, and obstructions from an accumulation of silt were not as liable to occur.

The broad flat bottom in both kinds of tile was, however, a defect of considerable importance, especially when they were carelessly laid. When the fall was slight, and but little water was running in the drain, the force of the diffused current was not sufficient to move the particles of silt that happened to gain admission at the imperfect joints; while, with the same fall, when the water is confined to a narrow direct channel, the silt would be carried along and discharged at the

outlet of the drain. Moreover, in laying the flat-bottomed tiles, any inequality in the surface on which they rested tilted them to one side or the other, and produced irregularities in the bore of the drain that diminished its capacity, by checking the current of water.

Judge French sums up the defects of the flat-bottomed tiles as follows: "On the whole, solid tiles with flat-bottomed passages may be set down among the inventions of the adversary. They have not the claims even of the horseshoe form to respect, because they do not admit water better than round pipes, and are not united by a sole on which the ends of the adjoining tiles rest. They combine the faults of all other forms, with the peculiar virtues of none." Tiles with an oval, or egg-shaped bore were at once suggested to obviate the most obvious defect of the flat-soled tiles.

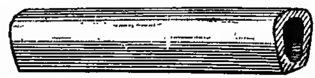


FIG. 10. EGG-SHAPED PIPE TILE, AFTER STEPHENS, 1848.

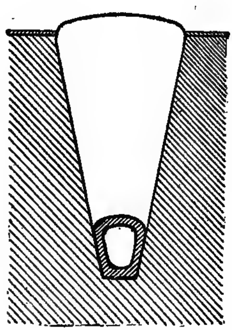


FIG. 11. THE SMALL PIPE TILE DRAIN, AFTER STEPHENS, 1848.

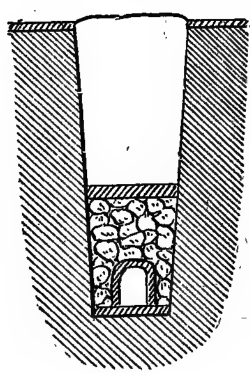


FIG. 12. THE TILE AND STONE DRAIN, AFTER STEPHENS, 1844.

Henry Stephens, in the article on draining, in his *Book of the Farm*, published in 1844, does not mention the "horseshoe pipe," the "egg-shaped pipe," or the "round-pipe" tiles, but in the edition of 1848 all three forms are described, and of these he says: "the most perfect form of the orifice for a pipe-tile is egg-shaped (fig. 10); the narrow end of the egg making a round and narrow sole, the water will run upon it with force, and carry any sediment before it; while the broad end provides a larger space for the water when it rises to the top after heavy rains." He thinks the bottom may be thought too narrow for "security against sinking," but he obviates this by making the bottom of the trench narrow and tapering, to fit the tile, as represented in fig. 11. This trench, he says, may be filled with earth, "but the best form of drain, in my opinion, is constructed with the egg-shaped tile and small broken stones, or clean large gravel," filled in to the depth of twelve inches, as

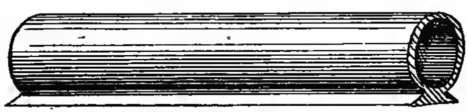


FIG. 13. OVAL SOLE TILE, AFTER FRENCH, 1859.

in fig. 12, the horseshoe and sole of his first edition (fig. 12) being replaced with the improved, or oval form of tile of fig. 11. The practical difficulty of making a trench, as in fig. 11, to secure a reasonable degree of accuracy in the alignment of the tiles, prevented the general adoption of this method, that looked so well on paper, and, moreover, it was found that the uneven shrinking of the clay in burning made the joints quite as imperfect as with the flat-bottomed solid sole. To give the egg-shaped tiles a more stable foundation the sole was widened, to give a broad foot, as shown in

fig. 13, but even this did not prove to be an advantage. Judge French says these sole-tiles are "much used in America, more, indeed, than any other, except perhaps, the horseshoe tile; probably because the first manufacturers fancied them the best, and offered no others in the market." Theoretically, this appeared to be a perfect form of tiles, but practically they were open to most of the objections to the D sole tiles, as it was difficult to lay them to secure uniformity in the bore of the drain, and the open joints at the top readily admitted silt.

Stephens' Book of the Farm was for many years looked upon as an authority on all subjects relating to agriculture, and his directions for draining were closely followed by writers on that subject, notwithstanding

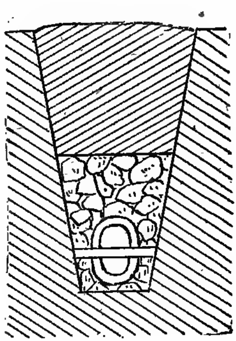


FIG. 14. AFTER DEMPSEY, 1869.

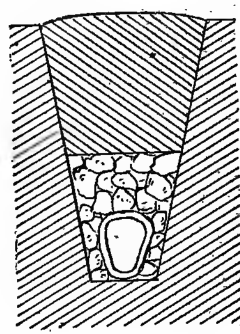


FIG. 15. AFTER DEMPSEY, 1869.

the better methods advocated by Parkes. As late as 1869, an English writer* recommends the form of drains represented in figs. 14 and 15, and the latter he considers "the most complete and undoubtedly permanent form of drain."

*Dempsey, On Drainage, p. 128.

There can be no excuse for these survivals of ignorance, as the best farmers had been practicing better methods for more than twenty-five years. The influence of Stephens and his followers kept alive the unfounded prejudices against round pipe tiles and retarded their general introduction as the only perfect form, as Parkes had clearly demonstrated. Stephens* devotes nearly two pages to an enumeration of the "practically objectionable" defects of round pipes, and to remedy some of the gratuitous difficulties his fancy suggests, he figures a number of devices for connecting the ends of the tiles, among which is the perforated collar, fig. 16, and he fully indorses the popular notion that water cannot readily gain access to a round pipe drain. With a better knowledge of correct principles, and improved methods of construction, we can now safely lay down the rule that round tiles should alone be used, as they have none of the defects of other forms, and they can be laid with greater accuracy and rapidity, and, on the whole, make much the best drain.

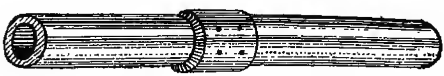


FIG. 16. PERFORATED COLLAR TO CONNECT ROUND PIPE TILES, AFTER STEPHENS, 1848.

Collars have frequently been looked upon as desirable by modern writers, especially when small tiles are used, but they serve no useful purpose, increase the expense, and they are now seldom used, as a better and more reliable drain can be made without them.

TILE DRAINING IMPLEMENTS.

The draining tools recommended from time to time by different writers have, with few exceptions, proved to be worthless, and it may be well to notice some of the

*A Manual of Practical Draining, 1848, pp. 91 92.

obsolete forms, as well as those that have a practical value in economizing labor.

The importance of diminishing, as far as possible, the amount of earth moved, by narrowing the trench towards the bottom, was at once recognized, when extensive draining operations were in progress, and special tools were invented for that purpose. The really improved implements were, in most cases, the outcome of the results of experience in the digging, and finishing of the bottom of narrow trenches, but, unfortunately, many of the draining tools placed in the market, and figured in works on draining, were evidently invented by persons who had no practical knowledge of what was required to accomplish the end in view, and they have proved to be useless. Spades of different widths, and somewhat tapering in the blade, to be used in succession to narrow the trench, were among the first improvements that proved to be of practical value. In fig. 17 is represented the spades used in making the trench for flat-bottomed tiles, and a slight change in form, fig. 18, was adopted in laying

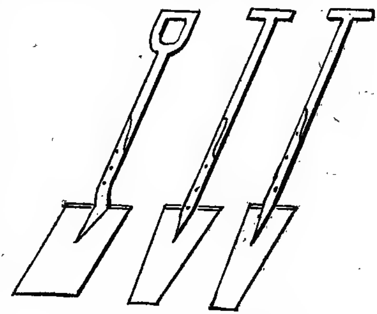


FIG. 17. DRAINING SPADES.

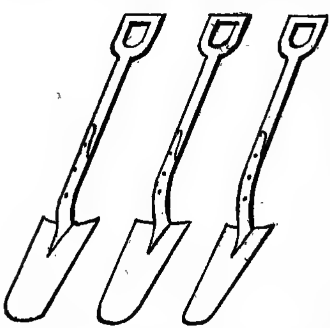


FIG. 18. ROUND-POINTED DRAINING SPADES.

round, or pipe tiles, the rounded point aiding in forming a groove in the bottom of the trench, in which the tiles are bedded. The draining spades now in use for cutting the lower part of a narrow trench, are of this same pattern, but the blade is made longer, which increases their efficiency.

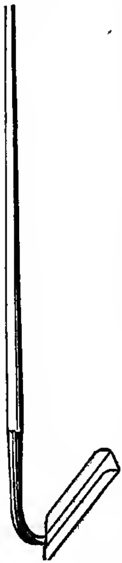


FIG. 19. PULL DRAIN SCOOP.

From the tapering form of these spades, they cannot be used to throw out the earth from the narrow trench which is cut with them, and scoops were invented for this purpose, and for smoothing the bottom of the trench, and preparing a suitable bed for the tiles.

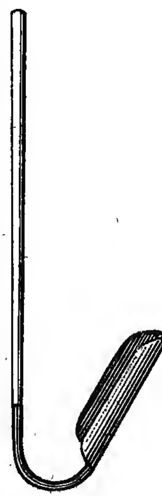


FIG. 20. PULL DRAIN SCOOP, FOR ROUND TILES.

In figs. 19 and 21 are two forms of scoop, figured by Stephens in his *Book of the Farm* in 1844. The draw, or pull scoop, fig. 19, was intended to be used for smoothing the bottom of the ditch for flat-bottomed and horseshoe tiles, and it was changed to the form represented in fig. 20, for laying round pipe tiles. It will be seen that earth cannot readily be thrown out of the ditch with this form of scoop, and the push scoop, fig. 21, was invented for that purpose. These scoops are, however, practically worthless in the hands of an ordinary workman; the pull scoops, unless very heavy, tremble, and are not readily guided; the push scoops are heavy on the point when loaded, and roll in the hands when raised to the surface of the ground, and from the attachment of the shank at the

end of the blade they are easily broken. On account of these, and many other defects which might be enumerated, they have not been used, to any extent, in draining. After a thorough trial of these scoops in a variety of soils, at the Michigan Agricultural College, several years ago, they were found to be useless, and finally consigned to the museum of obsolete implements. As a scoop was evidently needed to supplement the draining spades in excavating narrow trenches, I succeeded, after a number of experiments, in inventing a combined pull and push scoop, that was free from the defects of the old forms, a description and figure of which were published in the Report of the Michigan Board of Agriculture for 1873. After an experience of several years, in all kinds of soils, this scoop (fig. 22) has proved to be a satisfactory tool, in every respect, for removing earth from the trench and preparing a bed for the tiles; as it is light and well balanced, and, from the position of the shank in the middle of the blade, it is much stronger than the old forms.

FIG. 21. PUSH DRAIN SCOOP.

FIG. 22. MILES' DRAINING SCOOP.

An improved method of using this scoop will be given in the chapter on construction. A set of draining tools, copied from Gisborne's Agriculture, 1854 (fig. 23), furnishes a good illustration of forms that cannot be used with advantage. The scoops and the tile-layer are intended for use from the banks of the ditch, but they are awkward and heavy tools, and it is almost impossible to lay tiles with them on a reasonably true grade.

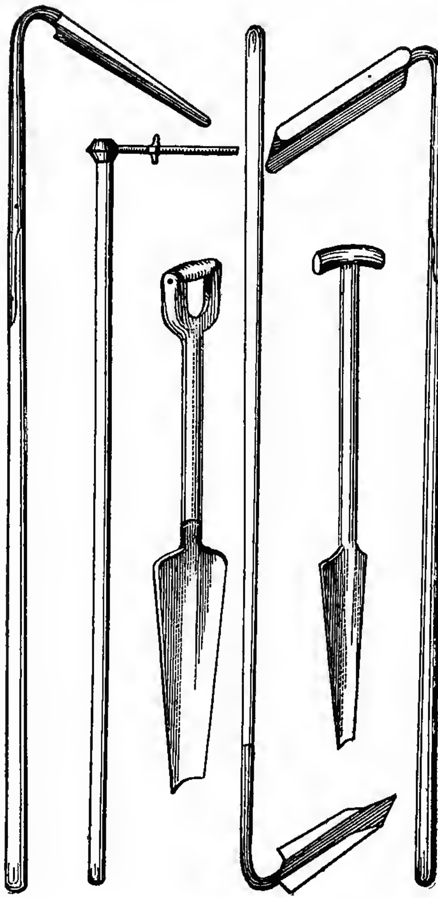


FIG. 23. OBSOLETE DRAINING TOOLS.

In directions for "opening the ditches," in *Draining for Profit and for Health*, Col. Waring gives a figure of a "finishing scoop" (fig. 24), and of a finishing spade, (fig. 25), which, according to my own experience, are quite as defective as the tools in the preceding figure. The curved sole of the scoop is not the best form for jointing a true grade, and the curved shoulder and square point of the spade do not recommend it as the best tool for making a narrow cut for round tiles. Modified forms of my draining scoop, which have been made and placed on the market, are represented in figs. 26 and 27. They are, however, too heavy for the intended purpose; the sides of the form, fig. 26, are too high for convenient use in adhesive soils, and there appears to be no practical advantage in the adjustable arrangement of the blade, represented in fig. 27, while it increases the weight of the scoop, which is a serious objection. The shovel scoop, described in chapter nine, for five or six inch tiles, and the lighter and simpler form of better proportions, figs. 22 and 30, for smaller sizes, will be found, in every respect, much more convenient and satisfactory than these heavier implements.

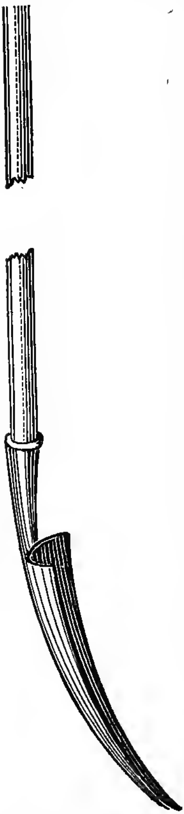


FIG. 24. FINISHING SCOOP.

FIG. 25. FINISHING SPADE.

The large handles and heavy blades of the so-called *improved* draining scoops in the market are defects that materially diminish their value, without any compensating advantages. A few ounces of unnecessary weight in a tool with a long handle, to move earth in the bottom

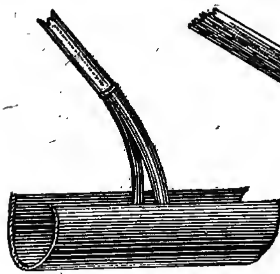


FIG. 26. DRAINING SCOOP.

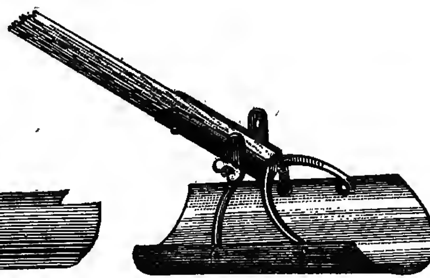


FIG. 27. ADJUSTABLE DRAINING SCOOP.

of the ditch, will be found a severe tax upon the muscular energies of the workman in the course of the day, and diminish his efficiency accordingly. The weight must be raised on the long arm of the lever, and the effective force required to lift it is proportionately increased.

CHAPTER VII.

Location and Plans of Farm Drains.

To secure efficiency and economy in the construction of farm drains the work should be planned, and the location of the drains decided upon over the entire area that may need draining, in accordance with a definite and well-matured system, in which every condition that may influence the results has been fully considered and provided for. When but part of the work can be done in a single season, the advantages of a complete plan for the drainage of all lands that can discharge water at a common outlet, before any drains are made, must be obvious, as each line of tiles laid will then form a consistent link in the general system, and the losses that are likely to arise from a change of plan in the progress of the work will be avoided. There are certain principles to be kept in mind in planning a system of drainage that it may be well to notice before discussing other details.

Direction of Drains.—In the first place, all drains should run directly down the slope, in the line of steepest descent, in order to secure the greatest efficiency in the discharge of water, in connection with the widest distance between the drains that can be made, and at the same time secure thorough drainage over the entire area to be drained. Any considerable variation from this rule should only be made for good and sufficient reasons, to secure other advantages that fully compensate for any faults that may arise in deviating from the most direct course.

It will readily be seen that when parallel drains are laid directly across the slope, a drain can receive no water from the space immediately below it, and that it must receive water from the whole width of the space between it and the next drain above. Moreover, when the slope of the field is considerable, these transverse drains allow water to escape at the joints of the tiles and wet the soil of the space below them, and thus add to the duty of the next drain. Many instances have come under my observation, where water from springs has escaped from drains laid across the slope, and saturated land which before was comparatively free from drainage water, the drains only serving to transfer the springs from one locality to another.

On the other hand, when drains run directly down the slope, they receive water from but one-half of the space between adjacent drains; impervious strata that bring water to the surface to form springs, are cut across; the water table is uniformly lowered; and the flow of water from one drain to another does not take place. The drains can then be laid at wider intervals, and the cost of thorough draining materially diminished. Parallel drains at equal distances are desirable, but when the slope of the field is not uniformly in the same direction they cannot be so made, and at the same time run directly down the slope in the line of the most rapid fall. Good judgment will then be required to secure a happy mean between the conflicting requirements, that will give the best results, but, as a general rule, the line of greatest descent should be the dominant factor in determining the location of the drains.

Main Drains.—A sufficient outlet must be secured for the main drain, and it should then be laid in the lowest ground, without any abrupt changes in fall, to check the flow of water passing through it, and it may be necessary to lay it at a greater depth from the sur-

face in some places, to secure the desired uniformity in its slope or rate of fall, and, if possible, there should be an increase in fall towards the outlet. When the fall in the upper course of a drain is considerable, and but a slight fall can be secured in its lower course, a larger tile will be required where the fall is diminished, to carry the water received from above, and prevent it from being forced out at the joints by the pressure from the head of water in the upper course of the drain, and thus undermining and displacing the tiles.

If the valley through which the main is to be laid is broad and nearly level from side to side, a sub-main should be laid on each side of it, near the foot of the slope, to avoid the rapid decrease in the fall of the lateral drains, that would be made if they were continued to the middle of the valley, and the space between the sub-mains may then be drained by laterals of smaller tiles. When a change in the direction of a main, or sub-main, is necessary, it should be made gradually, or with a gentle curve, as abrupt angles check the current of water and materially diminish the capacity of the drain. This fact should be kept in mind in all cases, but in the upper course of laterals, laid with two inch tiles, this is not as important, as they are not as likely to run full.

Depth of Drains.—It is important that the depth at which drains are to be laid should be decided upon before laying out, or determining their location in the field. Those who have had no experience in draining land are liable to fall into the error of laying the tiles too near the surface, from mistaken notions of economy. Practically the depth of retentive soils, as we have seen, is limited by the surface of the water table, and the drains should, therefore, be laid at sufficient depth to secure a free range of root distribution throughout the largest mass of soil that can be made available, with reasonable economy in construction.

The roots of nearly all of our cultivated crops penetrate the soil, under favorable conditions, to the depth of, at least, four feet, and this may safely be recommended as a desirable depth for laterals, while the mains, if possible, should be laid at least their own diameter deeper. There can be no doubt that drains four feet in depth have a number of advantages over those that are shallower, that must more than compensate for a considerable increase in cost, but it does not follow, however, that the draining of a field to the depth of four feet is necessarily more expensive than draining to the depth of three feet.

On the ground of efficiency, it appears that when heavy rainfalls occur after a season of drouth, the discharge of water begins sooner and continues longer; a larger mass of soil, with its supplies of nutritive materials, is made available for growing crops by the processes of metabolism; a wider range of root distribution is secured; and there is an increased capacity for holding capillary water for the purposes of vegetation in time of drouths. The extreme climatic conditions of excessive rainfall and intense drouth are, therefore, more completely corrected, and a greater uniformity in productiveness may reasonably be expected. The item of economy in the construction of four-foot drains will be considered in the next paragraph.

Distance Between Drains.—No absolute rule can be laid down as to the proper distance between drains, to secure the best results at the least expense. Good judgment in the application of general principles will be found the best guide in each particular case. The conditions that have an influence in determining the most desirable distance between drains are, the depth at which they are laid, the character of the soil, and the amount of rainfall that is likely to occur in single showers, or within a few days, which is of greater importance than the annual rainfall.

In order to secure the same efficiency in removing water from the soil, drains but three feet deep must be laid nearer together than when they are four feet deep, and the expense of draining a given area may, therefore, be less with the deeper drains, as the cost of digging the additional foot in depth of the four-foot drains will be compensated for by a saving in tiles, and in the number of ditches that are required. On the score of economy, as well as efficiency, the four-foot drains will undoubtedly prove most satisfactory. Mr. Parkes' table 21, (page 114), may be profitably studied in this connection.

The character of the soil should be carefully studied, and its behavior, as the drains are laid, should be closely observed. In the most retentive soils, when the drains are four feet deep, it will seldom be necessary to make the distance between them less than twenty-five or thirty feet, and in many soils, that need draining, a distance of fifty to sixty feet may give satisfactory results. The amount of rainfall should be considered, in connection with other conditions, as it may be of assistance, in some cases, in deciding upon the most desirable distance. The depth of drains is, however, a more important factor in preventing injury to crops from excessive rainfall than the distance between them.

Map of the System of Drainage.—In all cases it will be desirable to make a map of the field, or the area to be drained, on which the location and depth of every drain is accurately recorded. The general details of the map should be in black ink, and the proposed drains laid down with dotted red lines. As fast as the drains are finished the dotted line can readily be changed to a continuous red line, and a record may thus be conveniently kept of the progress of the work. When the work is not all done in a single season, the importance of an accurate map of the drains already made, as a means of definitely locating them, in order to form junc-

tions with the drains in process of construction, will be obvious. When the drains are all completed it may be necessary to find a particular drain, in case of obstruction, or for other reasons, and the map will then be found a great convenience and a saving of labor.

Locating Drains and Making the Map.—There are two methods of locating the drains and plotting them on the map, each of which has its advantages. An engineer, to secure accuracy and conformity to a definite plan in all parts of the work, would make a topographical survey of the area to be drained, by taking levels at frequent and regular intervals over the field, which would be represented on the map by contour lines, or lines of equal elevation, to indicate the shape of the surface. These would serve as guides in locating the drains so that they would run directly down the slope, or perpendicular to the contour lines, and the depth and rate of fall would be marked on the line of each drain. The entire system of drainage would, therefore, be first laid down on the map, and the drains in the field would be staked out from this record, as the work of construction was carried on. There are cases, perhaps, in which the expense involved in this method would be saved in economy of construction, if the engineer making the surveys was an expert in land draining.

Farmers who lay out the drains on their own farms, and carry on the work of construction as labor can be spared for the purpose, will, however, prefer a simpler and less expensive method, which answers quite as well, if a reasonable degree of intelligence or common sense is exercised in its application. Instead of making a plan on paper to serve as a guide in the field, the drains will be first staked out in the field from time to time, as required in the progress of the work, and they can then be plotted on a map with sufficient accuracy to serve all practical purposes of a convenient and permanent record,

without making use of any expensive surveying or engineering instruments.

All that is absolutely required in the field work is the means of accurately measuring the lines of drains, and their distance from certain land marks. A surveyor's chain, or tape, will be found convenient, but in their absence a rod pole, divided in feet and inches, will serve the purpose of providing the data for making a record of the work on the map. The cheap measuring tapes in common use should be discarded, as they are not always accurate, and if wet they are liable to stretch and vary in length, and the results obtained with them are often misleading.

When the surface of the field is undulating there will be no difficulty, in most cases, in deciding upon the location and course of the proposed drains by the eye alone, without taking levels with an instrument, but the precaution should always be taken when the fall is slight, to look over the proposed line from both ends of it before deciding upon its exact location, as appearances are sometimes deceitful if we look in one direction only. A farmer who is familiar with his fields, and observes the direction water flows over the surface in the spring, will seldom hesitate in regard to the direction of the slope and the course of lines running directly down hill. In cases of doubt as to the fall, on land that is nearly level, a simple and convenient method of determining the slope, or grade, of the drain, will be given in the chapter on construction.

Writers on draining have, with few exceptions, given directions for digging and finishing the ditches throughout their entire length before any tiles are laid, and when this is done, directions are given to lay the first tiles at the upper end of the drain and continue the work towards the outlet. This method is, however, impracticable, if there is water running in the ditch, or

if quicksand is found anywhere in its course, and in all cases better work can be done by beginning at the outlet to lay the tiles, and the ditch should only be finished as the tiles are laid. The main drain should always be laid first, to furnish an outlet for the discharge of water that may be running in the ditches in the progress of the work of construction.

In laying out and mapping the drains, attention will, therefore, be first directed to the main, and the laterals, or branches, will then follow in the order of their importance. Having placed stakes in the field to mark the line of the main drain, its place on the map may be determined, as follows. To facilitate the description of the different steps in the process, let us suppose a case in which the main drain crosses the north line of the field at, or near, the outlet.

Set a stake marked *A* at the point where the drain crosses or intersects the north line of the field, and determine its position by measuring on the boundary line of the field, in either direction, as may be most convenient, to the corner of the field, or to some permanent object, and make a record of this distance and position of the stake on the map, which should, of course, be drawn to a definite scale. Then set a stake marked *B* at the upper end of the proposed drain, or at the point where a change in direction will be necessary. Measure the distance from *A* to *B*, and to determine the exact course take the range of the two stakes, and ascertain where the line between them would, if continued, strike the opposite side of the field, and drive a stake marked *b* to mark the place. The position of *b* can now be determined by its distance from the corner of the field, or some permanent object, measured on the south line of the field, as was done to fix the point *A* on the north line. The drain *A–B* can now be plotted on the map by marking the point *A* on the north boundary of the

field, and the point *b* on the south boundary, and a rule touching the two points will give the course and position of the drain. The point *B* is then fixed by laying off the proper distance from *A* on this line.

If the main drain is now to be continued in a different direction, place a stake *C* at the end of the next course, ascertain where the line *B–C*, if continued, would intersect the boundary of the field, by taking the range of the two stakes, and mark the place with a stake *c*, the position of which is determined by its distance from *b*, or from any other known point, as in fixing the position of *A* and *b*. In plotting, place the rule on the map touching the points *B* and *c*, and measure on the line indicated the proper distance from *B* to *C*.

To locate the laterals proceed in the same way, taking as the starting point their junction with the main drain. If, for example, they are branches of the drain *A–B*, fix the point of junction by measuring the distance from *A*, or, if on the line *B–C*, determine the distance of the starting point from *B*. The laterals are then plotted on the map, by measuring their length from the main, and fixing their course, by ascertaining the point at which the line, if continued, would intersect the boundary of the field, and proceed as before. If there are several parallel laterals, the course of one may be fixed as above, and this may be taken as a base line from which the others may be laid out or located.

The whole process of locating and mapping the drains by this empirical method is so simple, that any one of average intelligence should be able to perform the work without any technical knowledge of surveying or engineering; and if the measurements are accurately made and the figures representing distances are entered on the map in their proper place, the record will be sufficiently accurate, even if the greatest exactness is not secured in drafting the lines on the map. A con-

venient scale for the map is fifty feet to the inch, but a scale of one hundred feet to the inch will give satisfactory results when there are but few drains to be recorded. As the drains are all located and staked out in the field, the map may consist simply of an outline of the field drawn to a definite scale, on which the lines of drains, as decided upon, may be drawn, with figures representing all distances, and letters or numbers to indicate each particular drain.

CHAPTER VIII.

QUALITY AND SIZE OF TILES.

There are a number of particulars in regard to the selection of tiles, that should receive careful attention, as the best for the purpose are the cheapest, if the draining of land is made, as it should be, a permanent improvement.

Round Tiles.—In describing the different kinds of tiles the conclusion was reached that round tiles should be exclusively used, as they have none of the defects of other forms, and it may be well to notice more particularly some of their most important advantages. When but little water is running in a drain of round tiles, it is confined to a narrow channel, and the force of the current is thereby increased, so that obstructions from silt are not likely to occur. The ends of the tiles vary but little from a right angle to the axis, and close-fitting joints can be secured in laying them, by turning them in their bed, if necessary, as it is a matter of indifference which side of the cylinder is up. When laid in the groove prepared for them by a draining scoop of proper size, they are not liable to be displaced by firmly

packing the soil with which they are covered. They can be laid more rapidly on a true grade than any other form of tile, which is a matter of importance where there is but little fall.

Quality of Tiles.—Tiles should be smooth and straight, with a uniform bore, and well burned, so that they give a clear ring when struck with a hammer. A permanent drain cannot be made with soft and porous tiles, as they readily yield to pressure when saturated with water, and when near the outlet they crumble in pieces, from the action of frost. On the other hand, tiles that have been "melted," or "over-burned" in the kiln, are to be avoided, as they shrink more than well-burned tiles, and the bore is, therefore, contracted, and they are usually more or less warped, so that they cannot be accurately laid in the trench. If used at all, they should be placed at the upper end of laterals, where they cannot check the current from any considerable length of the drain above them. On the whole, it is better, in buying tiles, to reject the over-burned as defective, as they not only impair the efficiency and durability of a drain by their contracted bore, but they add to the expense of laying them, from the difficulty of matching them to form good joints, and keeping a reasonably uniform grade in their course.

The weakest link in a chain is the measure of its strength, and the most defective tile in a drain is an index of its reliability throughout its entire course. Tile drains should be made on the plan of the "Deacon's One Hoss Shay," each part being as perfect as every other part, with no weak place to give out. Glazed tiles are now made in some localities, and they are always to be preferred when they can be obtained at the same price as the unglazed pipes.

How Does Water Enter Tile Drains?—The popular notion that porous tiles are necessary to insure

the free access of water to a drain is founded in error, and it has led to serious mistakes in construction. Its absurdity must be seen by reversing the conditions and considering the prospects of successfully conveying water from a spring, for any distance, in pipes that have open joints every twelve or thirteen inches in their course. It would at once be said that failure would surely follow, as the water would *leak out at the joints.* That water must leak in through similar joints in a tile drain, should likewise be obvious, and serve as a ready explanation of the manner in which water finds its way into drains. A simple experiment, which I have made before my classes for several years, should be tried by those who have any doubts in regard to the leakage of the joints of tile drains. Put a plug of soft wood, or cork, in one end of an ordinary unglazed tile, and then fill it with water. If the tile is then allowed to stand for an hour, it will be seen that the surface of the water is lowered but little by the amount absorbed by the walls of the tile, and that this would be insignificant in its effects in draining land. Then place another tile on top of the one containing water, and turn it around, to make as tight a joint as possible at their junction, and again pour in water to fill the second tile. It will then be found that the water escapes from the joint between the two tiles quite rapidly, and that a continuous stream of water is required to keep the second tile full, and that when the supply is cut off the leakage empties it in a few seconds. If the attempt is made to keep water out of a tile drain as laid in the soil, great care must be exercised in cementing the joints to make them water tight.

Gisborne,* on the authority of Parkes, makes the following statement: "If an acre of land be intersected with parallel drains twelve yards apart, and if on that acre should fall the very unusual quantity of one inch

*Essays on Agriculture, p. 108.

of rain in twelve hours, in order that every drop of this rain may be discharged by the drains in forty-eight hours from the commencement of the rain (and in a less period that quantity neither will, nor is it desirable that it should, filter through agricultural soil), the interval between two pipes will be called upon to pass two-thirds of a tablespoonful of water per minute, and no more. Inch pipes, lying at a small inclination, and running only half-full, will discharge more than double this quantity of water in forty-eight hours. The mains, or receiving drains, are, of course, laid with larger pipes." Having arrived at the conclusion that water enters drains at the joints between the tiles, and that what soaks through the walls of the most porous tiles is not worth considering, we may turn our attention to other points of practical interest relating to the behavior of drainage water in the soil.

How Does the Rainfall Reach the Tiles?—Let us trace the course of the rain falling on the soil until it reaches the tiles, in a field that has drains four feet deep, at regular intervals of forty feet. The water would at once be absorbed by the soil of a well drained field, and percolate directly downward by gravitation to the water table, which we will suppose, at the beginning of the shower, is just below the bottom of the drains. Over the entire field the water must then filter through more than four feet of soil before it reaches the water table, which will then gradually rise until it is above the bottom of the drain. The water will leak into the drain at the lower part of the joints between the tiles, and be discharged towards the outlet. In the case of moderate rains, that reach the water table, it must be evident that but a slight rise of the water table will take place when the drains begin to run, as the discharge and the supply will soon be equal, and it must likewise be seen that the water enters the drain from below, and it is only

when the rain is sufficient to raise the water table to the top of the tiles that water can leak in on all sides of the joints of the tiles.

From the failure to recognize these facts the mistake has often been made of filling the ditch immediately above the tiles with permeable materials, as small stones, or gravel, to facilitate the percolation of water to the top of the drain, as shown in figs. 4, 12, 14 and 15. This does more harm than good, to say nothing of the unnecessary expense, as silt is liable to be washed into the drain at any defective joint, by water entering freely at the top of the tiles, and care should be taken to pack the earth firmly above the tiles, so that water may be forced to continue its downward course through the soil to the water table, before entering the drain.

When the discharge from the drains equals the supply of water from above, the water table does not rise any higher, and this marks the maximum flow of water through the drains; and when the rain ceases the water table soon begins to fall, and the flow from the drains diminishes. Moreover, as soon as the drains begin to run there must be a movement of the drainage water in the soil towards the drain, to replace that discharged through the tiles, and this lateral movement gradually extends to the distance of twenty feet on each side of the drain, in the case supposed above, or one-half the distance to the adjoining drains. The rain, falling directly over the drain, reaches the water table and leaks into the tiles, with but slight lateral percolation through the soil; while that falling half way between the drains makes a vertical descent of four feet to the water table, and is then carried, by the lateral movement of the drainage water, to the drain, having percolated through the soil a total distance of twenty-four feet. From the extent of this filtration of the rain through the soil, some time must elapse before the water, falling on the

surface of the soil, can begin to escape by the drain, and, after the rain has ceased, the drains must continue to run until the water table subsides to the level of the bottom of the bore of the tiles, which must take place gradually, from the lateral distance a large proportion of the water must percolate through the porous soil before reaching the drain.

There is another factor that has an influence on the time required by the rain-water to reach the drain, that must not be overlooked. The capillary capacity of the soil must be satisfied before any of the rainfall assumes the form of drainage water. Soils have, as has already been pointed out, a certain capacity for retaining or holding capillary water, and, in the intervals between rains, in the growing season, this store of water is drawn upon by exhalation from plants, and surface evaporation from the soil. When rain falls it is, in the first place, appropriated by the soil to replenish its stock, or normal reserve, of capillary water, and it is only the rain in excess of this demand that appears as drainage water. In the wheat experiments at Rothamsted, it was stated that the drains of the barnyard manure plot, on the average, run but once in the year, and quite heavy rains in the growing season, under ordinary conditions, frequently fail to bring about a discharge from the drains.

Direct observations have repeatedly shown that the mass of drained soil above the tiles has a marked influence, in retarding the flow of drainage water and in diminishing its volume. After a rainfall of nearly half an inch in twelve hours, Mr. Parkes found that the discharge of drainage water, by Mr. Dickinson's Dalton gauge, and by Mr. Hammond's inch pipes, laid three and four feet deep in a field, continued forty-eight hours after the commencement of the rain.

With heavy rainfalls on retentive soils, a considerably longer time is required for the discharge of the

drainage water. In Central Park, New York, soon after the drainage of "the Green" was completed, comprising an area of about ten acres of wet land, Col. George E. Waring, the engineer in charge, made frequent estimates of the volume of water discharged by the main drain, from July 13th to Dec. 30th, to ascertain the relations of drainage to rainfall. The results of these observations for the first month (July 13th to Aug. 14th), given in the following table, will sufficiently illustrate the gradual discharge of the drainage water, without copying the record in full.*

It will be seen that three remarkable rains occurred in the course of the month recorded in the table, viz.: July 12th and 16th, and Aug. 5th, and that the total fall of rain for the entire period was 171,052 gallons per acre (7.57 inches), of which but 45,252 gallons per acre (2.00 inches), or 26.46 per cent. was discharged by the drains. A large proportion of the first rainfall of 2.20 inches (July 12th) must have been retained by the soil, as the maximum recorded discharge from the drain (July 14th) was at the rate of only 9.95 per cent. of the rainfall in twenty-four hours, or about one-fifth of an inch, and the discharge the next two days was at the rate of less than three per cent. of the rainfall in twenty-four hours. The total discharge from the drains in three days was less than fifteen per cent. of the rainfall, and the soil at the depth of two feet was still saturated with (capillary) water. The second heavy fall of rain occurred July 16th, followed by a decided increase in drainage, but even then the rate of maximum discharge was only at the rate of 23.25 per cent. of the rainfall, or a little over one-third of an inch in twenty-four hours. The drainage then rapidly diminished, but the effects of these two rains of over three and one-half inches was evident until the 3d of August, or more than two weeks.

*Draining for Profit and Health, p. 87.

TABLE 22.

RAINFALL AND ESTIMATED DISCHARGE BY THE DRAINS IN CENTRAL PARK, IN GALLONS PER ACRE, WITH PERCENTAGE OF PRECEDING RAINFALL IN DRAINAGE IN 24 HOURS.

Date.	Hour.	Rainfall. Galls. per acre.	Drainage. Galls. per acre.	Per cent. of preceding rainfall in drainage in 24 h'rs.	Remarks.
					Ground dry. No rain since 3d inst.
July 13,	10.00 A. M.	49,916=2.20 inches	184		2 inches of rain fell between 5.15 and 5.45 P. M., and ⅕ of an inch between 5.45 and 7.15. (12th inst.)
July 14,	6.30 A. M.		4,968	9.95	
July 15,	6.30 A. M.		1,325	2.65	
July 16,	8.00 A. M.		1,104	2.21	
July 16,	6.00 P. M.	33,398=1.48 inches	7,764	23.25	Ground saturated at a depth of 2 feet when this rain commenced.
July 17,			4,319	12.93	
July 18,	9.00 A. M.		2,208	6.62	
July 19,	7.00 A. M.		1,325	3.97	
July 20,	6.30 A. M.		993	2.97	
July 21,	11.00 A. M.		662	1.98	
July 22,	6.30 A. M.		560	1.68	
July 23,	10.00 A. M.	1,698	515	1.54	This slight rain only affected the ratio of decrease.
July 24,	7.00 A. M.		442	1.26	Nothing worthy of note until Aug. 3d.
Aug. 3,	6.30 A. M.	8,490	191	0.54	Rain from 3 P. M to 3.30 P. M. (Aug. 2d).
Aug. 4,	6.30 A. M.	13,018	184	0.42	Rain from 4.45 P. M. to 12 night.
Aug. 5,	6.30 A. M.	45,288=2 inches.	368	2.83	Rain from 12 M. to 6 P. M.
Aug. 5,	6.00 P. M.		8,280	18.28	
Aug. 6,	9.00 A. M.		3,954	8.73	
Aug. 7,	9.00 A. M.		2,208	4.88	
Aug. 8,	6.30 A. M.		828	1.83	
Aug. 9,	6.30 A. M.		662	1.46	
Aug. 12,	6.30 A. M.		368	0.81	Rain 12 M. Aug. 12
Aug. 13,	7.00 A. M.	19,244=0.85 inches	1,104	5.74	to 7 A. M. Aug. 13.
Aug. 14.	9.00 A. M.		736	3.82	
Totals,		171,052 gals=7.57 in	45,252 gals=2.00 in	26.46	

The slight rains of July 23d and Aug. 3d had little, if any, influence on the drainage, and there was but a slight increase from the rain of over half an inch on the 4th of August. We find, likewise, that the greatest discharge from the drains did not follow the heaviest rainfall, and that the smallest of the three heavy rains gave the largest percentage of drainage. This is best shown in the tabular form as follows:

TABLE 23.

Date.	Rainfall in inches.	Maximum discharge by drains in 24 hours in gallons per acre.	Per cent. of rainfall in maximum drainage in 24 hours.
July 13th	2.20	4,968	9.95
Aug. 5th	2.00	8,280	18.28
July 16th	1.48	7,764	23.25

The maximum rate of discharge of water by the drains, after a rainfall of 2.20 inches, is but sixty per cent. of the discharge after a rainfall of two inches, and less than sixty-four per cent. of that following a rainfall of but 1.48 inches, and the drainage is not, therefore, determined solely by the amount of rainfall.

The tables of drainage and evaporation, in chapter three, may be profitably consulted in this connection. The relations of drainage and evaporation to rainfall show that it is not necessary to provide drains to carry off all of the heaviest rainfalls. The stores of capillary water in the soil are materially diminished by evaporation from the surface soil, and exhalation by plants, in the growing season, and quite copious rains may be required to replace what has thus been disposed of.

It is, however, evident that the influence of soils in retarding the discharge of drainage water, must vary with their capacity to absorb and retain water, in connection with their previous condition of dryness, and the observations made at Central Park, and in other drainage experiments, must be interpreted as representing a conformity to the general law that determines the

percolation of water through soils, under the special conditions presented in each case. The known facts in regard to the comparatively small proportion of the average rainfall that is discharged as drainage water from well drained retentive soils, on which a crop is growing, and the time required for it to reach the drains, must then be recognized, as important factors for consideration, in deciding upon the capacity of drains that are needed to secure thorough drainage.

Size of Tiles.—As the prices of tiles increase rapidly with their size, and their cost forms an important cash item in the expense of draining, it will be desirable to use the smallest sizes that will serve the purpose of promptly discharging the drainage water that may reach them after heavy rains, under ordinary conditions.

The tables, in works on draining, giving the capacity of pipes at different inclinations, for discharging water, are of no practical value as aids in determining the size of tiles required to carry off the surplus water of a given rainfall, as they do not take into account the different ways soil water is disposed of, or the many conditions that prevent its rapid percolation through a drained soil on its course to the drains. The principles of hydraulics are applied in estimating the required capacity of sewers for removing a given amount of water, which they receive directly through the open mouths of their branches, but they do not have the same significance in land drainage, from the indefinite and constantly varying factors intervening between the fall of rain upon the surface of the soil, and the access of drainage water to the tiles; so that it is impossible to formulate the direct relations of drainage to any given rainfall.

Most of the empirical rules that have been given for estimating the required capacity of tiles for draining a given area, will lead to the selection of sizes considerably larger than are actually needed, and thus unneces-

sarily increase the expense. For example, Gisborne* lays down the rule "that a three-inch pipe will discharge the water of nine acres, four of sixteen, and so on; the quantity of acres being equal to the product of the diameter of the pipe in inches multiplied into itself." Waring makes the following estimate, which is, undoubtedly, a safe one, under average conditions. "In view of all the information that can be gathered on the subject, the following directions are given as perfectly reliable for drains four feet, or more, in depth, laid on a well regulated fall of even three inches in a hundred feet:

For 2 acres 1¼ inch pipes.
For 8 acres 2¼ inch pipes.
For 20 acres 3½ inch pipes.
For 40 acres two 3½ inch pipes.
For 50 acres 6 inch pipes.
For 100 acres 8 inch pipes.

"It is not pretended that these drains will immediately remove all the water of the heaviest storms, but they will always remove it fast enough for all practical purposes, and, if the pipes are securely laid, the drains will only be benefited by the occasional cleaning they will receive when running 'more than full.'"†

The size of the main should be determined with reference to the area to be drained, without taking into consideration the combined capacity of the laterals connected with it. In a well-planned system of drainage the combined capacity of the laterals will almost always considerably exceed the capacity of the main required for a given area. So far as their capacity to discharge water is concerned, one-inch pipes are sufficient for laterals under average conditions, and they have been extensively used in Great Britain, where they seldom run more than half full after heavy rains. From their small

* Essays on Agriculture, p. 109.
† Draining for Profit and Health, p. 88.

section, however, they are liable to displacement, and any slight irregularities in the fall on which they are laid will check the flow of water through them and interfere with their efficiency, and for this reason laterals of one and one-half to two inches are, on the whole, to be preferred. In many localities two-inch tiles are uniformly used for laterals, as they are the smallest size made in the vicinity. When the fall is over six inches in one hundred feet, with a uniformly hard bottom, a slight saving might be made by using one and one-half inch laterals, but with a less fall, or when the bottom of the ditch is not firm, two-inch laterals have advantages, which, in my opinion, more than compensate for the difference in cost. In peaty soils, that are liable to settle, more or less, and thus interfere with the alignment of the tiles, three-inch laterals may be used with economy, but, on upland soils, where the tiles, when properly laid, are not likely to be displaced, they have no advantages over two-inch laterals under any conditions, or even over one and one-half inch tiles that have a fall exceeding five or six inches in one hundred feet.

An illustration of the capacity and efficiency of drains in actual practice may be of interest in this connection. Mr. A. F. Wood, of Mason, Michigan, has tile drains of four, five and six inches in diameter on his farm, which, in an experience of several years, have proved satisfactory as mains for the drainage of larger areas than the same sizes have been credited with in the above estimates. The first six-inch main was laid to take the place of a large open ditch that had failed as an outlet for the drainage of about one hundred and twenty-five acres. At the upper end of this main a well, or silt basin, was made, opening above the surface, so that the working of the drains could be readily observed. Sub-mains of three, four and five inches in diameter were laid in different directions from this well, and their

combined capacity, therefore, considerably exceeded that of the six-inch main, the ratio being about fifty to thirty-six.

The five-inch sub-main, sixty rods long, has branches of three and four inch tiles, connecting with about two miles of two-inch laterals, draining fifty acres. The four-inch sub-main receives the drainage from about twenty acres, on which there is more than three-fourths of a mile of two-inch laterals. On the whole, the six-inch main receives the drainage from more than three miles in length of lateral drains. Another six-inch main, seventy rods long, receives the discharge from forty rods of five-inch, and one hundred and forty rods of four-inch branches, with two-inch laterals to make up an aggregate of five miles of drains on an area of seventy-five acres. The fall of the several drains is approximately as follows: The first six-inch main seven inches in one hundred feet; the five-inch sub-main six inches in one hundred feet, and its laterals an average of two inches in one hundred feet; the second six-inch main four inches, and its laterals from one to one and one-half inches in one hundred feet. From observations at the well at the upper end of the first six-inch main, it appears that it runs full after heavy rains in wet seasons, or taken all together for three or four days in the course of the year, but it has never failed to remove the drainage water, so that the land could be worked within a few hours after the heaviest rains. In some years it has not been known to run full, although closely watched. On the whole, Mr. Wood informs me that the drainage of his farm has proved satisfactory in every respect, and he has do doubt as to the sufficient capacity of the main drains.

The nearest point at which a record of the rainfall has been kept since the drains were laid, is the Michigan Agricultural college, ten miles north in a direct line.

At that place the annual rainfall has varied from 23.78 to 48.36 inches, with an average of 34.15 inches for the ten years preceding 1890. From four to fifteen rains of one inch, or over, in twenty-four hours, have occurred in a year, or an annual average of nine for the entire period. Of these heavy rainfalls, in the course of ten years, there were thirty-five of one and one-half inches, or over; thirteen of two inches, or over; five of two and one-half inches, or over; one of three inches, and one of three and one-half inches.

Collars.—We have already expressed the opinion that collars for tiles are not necessary, but it may be well to examine in detail the claims that have been made for their use. They have been recommended for the smaller sizes of tiles to prevent any danger of displacement, and it has even been claimed that small round tiles should not be laid without them. An extended experience has, however, proved to my satisfaction that collars should never be used, as, from their first cost (about two-thirds as much as tiles), and the additional labor required in laying tiles with them, the expense of draining is materially increased, without any compensating advantages. The theoretical advantages of collars must be limited to holding the end of the tiles, to prevent displacement in the process of laying, in order to secure uniformity and continuity in the bore of the drain, but, to secure this desirable accuracy in alignment, the collars must fit the tiles closely, as they seldom do; and it must be seen that when the tiles are once covered and bedded in the earth, there is no further danger of displacement. In the finished drain collars can serve no useful purpose, as the assumption that they add to the security of the joints and prevent the entrance of silt may, with good reason, be questioned. Practically, the collars simply serve to conceal the defects arising from careless methods of construction, and with suitable

tools, in the hands of an intelligent workman, a better drain can be made without them.

Of the many objections which might be urged against the use of collars, we will only notice the most obvious. In burning tiles and collars, the heat to which they are subjected is not the same, at different times, or even in different parts of the kiln, and there ~~is~~ are, consequently, marked differences in shrinkage, so that uniformity in size cannot be obtained. From this fact it is difficult to select collars to fit the tiles as they are laid, which seriously retards the progress of the work. In the next place, there is no certainty that close joints between the ends of the tiles are made, as they are concealed by the collars, and when an open joint is made under a loose-fitting collar, silt readily finds its way into the drain, and may cause an obstruction.

Sometimes the tiles are laid without touching the bottom of the ditch, their ends being supported by the collars, and, when the drain is finished, there is a space under the tiles to be filled by the subsequent washing in of the earth. In such cases the tiles are liable to be broken by the pressure of the soil above them, or by carelessness in packing the earth with which they are covered. If, to avoid accidents of this kind, an excavation is made to receive the collar, and allow the tiles to rest on the bottom of the ditch, the expense of laying the tiles is considerably increased. Moreover, inch, or inch and one quarter tiles, with collars, will cost more than inch and one-half, or two-inch tiles without collars, so that, on the whole, the smallest sizes, with collars, cannot be recommended on the score of economy.

Summary.—The leading facts which have a bearing upon the question of the size of tiles required for thorough draining may be briefly stated, as follows: In the first place, it must be admitted that the flow of water in tile drains depends upon the level of the water

table, and that water enters drains at the joints of the tiles. In the growing season the exhalation of water by plants, and evaporation from the surface soil, are carried on at the expense of the capillary water of the soil, with the result that in dry seasons the water table is, to a greater or less extent, below the level of the drains.

The rain falling upon the surface of the soil, after an interval of drouth, is, in the first place, disposed of as capillary water, to supply the existing deficiency in the soil, and, in the next place, that which is not needed for that purpose percolates down to the water table, which gradually rises until it reaches the drains, and a flow of drainage water through the tiles then follows. A lateral movement of the standing water in the soil, between the drains, now sets in to supply the loss by drainage through the tiles.

In effect, then, the drained soil not only serves as a storage reservoir for the rainfall, but it retards its descent to the drains, so that the maximum discharge from the tiles takes place some time after the rain has fallen, and it soon diminishes to a moderate flow, that continues several days. The amount of water soils may absorb is very much in excess of any probable rainfall. The water held by the drained wheat soil, in January more than in July (table 16, p. 84), would represent seven or eight inches of rainfall; and the difference in the water contained in the fallow and barley land (table 18, p. 87), was equivalent to from seven to nine inches of rainfall. It was shown, in other experiments, that but a small proportion of the rainfall, in the summer months, was disposed of as drainage water, even in wet seasons; and that in the winter half of the year the drainage from a bare soil was, in no case, equal to the rainfall, and from a soil on which crops were growing it was very much less. The significance of these facts will best be seen by bringing together some of the results obtained in the preceding tables.

Of the extraordinary summer rainfall, of 25.75 inches, at Rothamsted, less than one-half appeared as drainage, while in all of the other observations the summer drainage was not only very small, but it was less from a soil where grass was growing than from a bare soil. The winter drainage varied from less than one-

TABLE 24.

RELATIONS OF DRAINAGE TO RAINFALL.

Drain Gauges.	Summer ½ year April-Sept.		Winter ½ year. Oct.-March.		Total for the year.	
	Rainfall inches.	Drain'ge inches.	Rainfall inches.	Drain'ge inches.	Rainfall inches.	Drain'ge inches.
Mr. Dickins'ns Av. 8 yrs, sod,	12.88	0.90	13.74	10.39	26.61	11.29
Wettest season, sod,	17.41	2.60	13.87	12.31	31.28	14.19
Mr. Greaves', Av. 14 yrs, sod,	12.14	0.73	13.58	6.85	25.72	7.58
Rothamsted, Av. 18 yrs bare soil,	15.21	4.04	15.24	10.35	30.45	14.39
Wettest sum'r	25.75	12.27	16.96	13.59	42.72	25.86
Geneva, N. Y. Av. 5 yrs, sod,	15.85	1.17	7.87	2.29	23.72	3.46
Wettest summer, sod,	18.55	3.84	9.32	3.72	27.87	7.56
Wettest sum'r bare soil,	18.55	4.71	9.32	5.16	27.87	9.87

half to rather more than three-fourths of the rainfall, with the single exception observed by Mr. Dickinson, in which the heavy summer rainfall of the wettest season increased the winter, as well as the summer, drainage.

It was only claimed for the Central Park observations, that they approximately represented the relations of drainage to rainfall, but they are consistent with the more accurate records obtained with drain-gauges, and they may, therefore, be accepted as representing a conformity to the general law. During the summer in which the drainage was observed, once or twice a day after every rain, the maximum discharge of water from the drains followed a rainfall of less than one-third of an inch, and it was at the rate of 0.44 of an inch of rainfall in twenty-four hours, at 9 A. M., August 25th; at

7 P. M. it had fallen to 0.39 of an inch; at 6.30 A. M., Aug. 26th, it was only 0.18 of an inch; and at 6 P. M. it was but 0.10 of an inch. The average of six observations of the drainage, in the three days following the maximum discharge, was at the rate of only one-fifth of an inch of rainfall in twenty-four hours, but this was only eleven days after the close of the month recorded above, in which nearly twice the average amount had fallen, including three rains of from 1.48 to 2.20 inches. The drainage, in this case, must have been influenced by the heavy rains of the preceding month. Rainfalls of two and one-half inches, or over, must be looked upon as extraordinary, and they so rarely occur in the Northern United States, that they need not be considered in estimating the required capacity of drains to secure thorough drainage. From the increased cost of tiles, and the labor required in laying them, it will not pay to provide for the discharge in a few hours of the surplus drainage of extraordinary rains that seldom occur. They are best provided for by deep draining, to increase the storage capacity of the soil, and prevent a rapid transfer of water from the surface to the drains, by the larger mass of soil through which it must percolate, and if the tiles are well laid, with close-fitting joints, on a uniform grade, the drains will not be injured by running full for several days under the increased pressure to which they are subjected.

On the other hand, from the evidence already presented, in regard to the behavior of soil water, the indications are that the surplus water of extraordinary rains cannot be disposed of in a few hours, under the most favorable conditions for its discharge by large drains, as time must be allowed for its percolation downwards to the water table, and for its more or less extended lateral movement through the soil between the drains, before it can escape through the tiles.

CHAPTER IX.

HOW TO MAKE TILE DRAINS.

To make an efficient and permanent drain, round tiles must be laid with close-fitting joints, on a uniform slope, without any vertical undulations to obstruct or check the flow of water through them, and, what is quite as important, they must be covered with earth, and the ditch filled, without displacing the tiles or interfering with their alignment. Every detail of the work should be carried out with unwavering attention to these fundamental requirements, which should be secured with the strictest economy in the expenditure of labor. In order to accomplish the desired end the work must be carried on in accordance with a definite, well-matured plan, and the implements best adapted to the purpose must be provided, before any tiles are laid.

Skilled labor, or, at least, skillful and intelligent supervision, is required, to make a tile drain that will prove satisfactory in every way, and keep its cost within reasonable limits. It has been estimated, by those who have given the subject attention, that at least three-fourths of the tile drains which have been made, have failed, to a greater or less extent, to give satisfactory results from errors in construction. To one who is familiar with the ordinary methods of draining, it is not surprising that the partial, or total, failures in tile draining are so numerous, as the work is frequently undertaken by those who have no definite knowledge of correct principles; and preconceived notions, or fallacious reasoning upon the facts presented, have often led to

easily avoidable faults in construction, and consequent disappointment in the results. Many of the mistakes made in draining may, however, be attributed to a reliance on authorities that are hastily consulted, as the errors of the early writers have, in too many instances, been copied, and even found their way into standard works on draining, without due consideration of their real import and impracticability.

After an extended and unsatisfactory experience in attempting to follow the directions for laying tiles found in books on draining, I was compelled to abandon them, and devise new methods to simplify the work of construction and secure a reasonable degree of accuracy in the finished drain. In the first place, it was found necessary, and it proved to be a fortunate innovation on accepted methods, to begin laying tiles at the outlet and work towards the upper end of the drains, instead of keeping long lines of ditch open, and trying to overcome the almost insuperable difficulties involved in following the directions uniformly given by writers on draining. With this change of base, many of the most serious obstacles which had before been encountered, entirely disappeared. In the next place, it was evident that the old methods of determining, or fixing, the grade of the drain, by means of "boning rods," "A levels," and similar devices, were not only inconvenient, but fallacious and unreliable, under average conditions, and attention was directed to an improvement of the methods for establishing the grade of the bed for the tiles.

Grade Fixed by a Line.—Judge French* had recommended a line, as "the most accurate and satisfactory method of bringing drains to a regular grade," but his method of adjusting and fixing the line above the ditch proved insufficient and unreliable, as it could not be readily fixed in the proper position, and was liable

*Farm Drainage, p. 233.

to displacement in the progress of the work. After numerous experiments, the method of adjusting the line, described below, was finally adopted, as the best and most convenient, and a description of it, with illustrations, was published in the annual report of the Michigan State Board of Agriculture for 1873, with the improved form of draining scoop already noticed (fig. 22, p. 126; and fig. 30, p. 160). Since that time the practical value of these improvements in tile-laying has been demonstrated in extensive draining operations, in economizing labor, and in the accuracy and permanent character of the results obtained. The directions for laying tiles, which follow, are the results of practical experience in the field, and the several steps in the process will be given in sufficient detail to answer all questions that are likely to arise in ordinary farm practice.

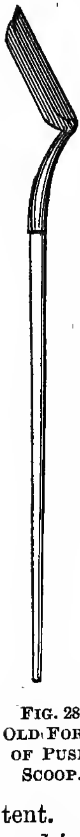


FIG. 28. OLD FORM OF PUSH SCOOP.

Tools Required.—Besides the simple appliances for adjusting the line, which will soon be noticed, and ordinary spades and shovels, a few "draining tools" should be provided before beginning draining operations of any extent. The tools that must be considered indispensable are three sizes of the draining scoop (figs. 22 and 30), for two, three and four-inch tiles, and two or three draining spades, with blades sixteen inches long, and from four to six inches wide at the point.

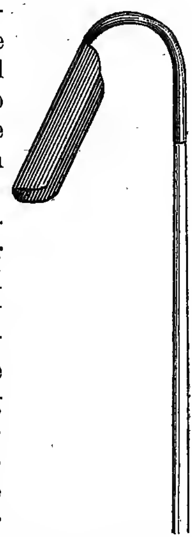


FIG. 29. OLD FORM OF PULL SCOOP.

The cost of these tools need not exceed six or seven dollars, and this will be saved, in economizing labor, in making but a few rods of drain, and, moreover, it will be exceedingly difficult to lay tiles, as they should be laid, without them. The draining spades can be obtained through any hardware dealer, who will order them, if not kept in stock. As the draining scoops may not be found in the market, a description will be given that will enable any intelligent blacksmith to make them. The blades, about twelve or thirteen inches in length, may be made of thin sheet steel, like a hand-saw blade, or the well-worn blade of an old shovel, the shank being secured in the middle by two rivets, with the heads countersunk on the under side, to make a smooth surface. The blades should be curved, to fit the outside of the tiles, for which they are intended to form the groove, or bed, in the bottom of the ditch. The width of the blades should be a little more than one-third, and rather less than one-half the outside circumference of the tile. The handles may be from four and one-half to six feet long, and about the size of the lower part of a common rake stale, or a small hoe handle; and the aim should be to make a light, handy tool, as great strength is not required in jointing the groove to receive the tile, or in throwing out loose earth from the bottom of the ditch. The draining scoops in the market, of the old form (figs. 28 and 29), may be altered to the improved form (fig. 30), by changing the position of the shank, but, as a rule, it will be better to use only the blade, and make a new and lighter shank and handle. Useful scoops for heavier work may be made by

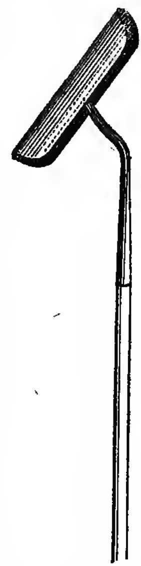


FIG. 30. MILES' DRAINING SCOOP.

cutting off the sides of an ordinary long-handled pointed shovel, so that the blade is about six and one-half or seven inches wide, and then curving it to fit the outside of a five or a six-inch tile. These can be used for clearing the earth from the ditch when it is too narrow for the ordinary shovel or spade, and to form the bed for five and six inch tiles, according to the curve of the blade. For convenience, this will be called the shovel scoop.

Ditches for Tile Drains.—As the cost of ditches depends, to a great extent, upon the amount of earth moved in digging them, their width should not exceed what is required to give sufficient room for performing the work of excavation and laying the tiles. With suitable tools, in the hands of an experienced workman, a ditch sixteen inches wide at the top, and tapering to four inches at the bottom, may be dug to the depth of four feet, with but little inconvenience, and that has its compensations in the comparatively small amount of earth moved in accomplishing the result. At the depth of from two to two and one-half feet, such a ditch would be ten or twelve inches wide, and, thus far, ordinary spades, or shovels, assisted by the pick, if necessary, will be the most convenient tools to use. This leaves ample room for the workmen, in making the remaining excavation. A sharp draining spade, with its rounded point, may now be used to advantage. From its tapering form, and the gradually diminishing width of the ditch, the earth chipped, or sliced off, with it, must be thrown out with a shovel scoop. The last spading of from six to ten inches should not be disturbed until ready to lay the tiles. A ditch from four to five inches wide at the bottom will serve for two-inch tiles, and a width of nine inches is sufficient for six-inch tiles, provided a straight trench has been made. Workmen, by the day, may prefer more commodious quarters to work

in, but when paid by the rod the discomforts of a narrow ditch soon cease to be a matter of complaint.

In order to lay tiles successfully in a narrow ditch, it must be straight, as any lateral curves will prevent the making of tight joints between the ends of the tiles as they are laid. This should be kept in mind throughout the entire process of excavation. A line drawn upon the surface should be the guide, in beginning the ditch, as a curve made on the start cannot easily be corrected as the excavation proceeds.

The use of the plow near the surface, and the subsoil plow to loosen the earth at greater depths, have frequently been recommended as labor-saving operations in digging ditches. If straight and narrow ditches are desirable, to economize the amount of earth to be moved, it is doubtful whether any saving in labor can be made by the use of the plow, on ditches for tiles from two to six inches in diameter. For the ditches required for larger tiles, it is possible that the plow, under judicious management, may be used with economy, but my experience leads me to doubt it. It should be remarked that the earth should always be thrown out on one side of the ditch, leaving the other side clear, for the distribution of tiles, and convenient access to the work for various purposes.

Adjustment of the Line.—In order to lay tiles on a uniform slope, which is especially necessary when there is but little fall, the grade, as we have seen, can be most readily established by measuring from a line, drawn over the middle of the ditch, at a convenient distance above the proposed bed of the tiles. To fix this line in its proper position, "shears" are used, consisting of two pieces of light wood, one inch thick and about three inches wide, and five to seven feet long, joined together near one end by a small carriage bolt, as represented in fig. 31. The lower end of the arms should be

square, to prevent settling in the earth when in position. In describing the method of adjustment and the use of the line, we will suppose that, beginning at the outlet, several rods of ditch have been dug to within six to ten inches of the bottom. Two of the shears are then placed astride the ditch, from four to six, or more, rods apart, one of them being over the point where the first tile is to be laid, and adjusted in height, by spreading, or contracting, the arms, so that they will hold the line seven feet above the proposed grade.

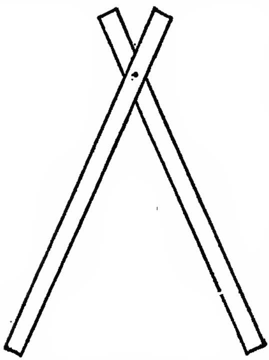


FIG. 31. SHEARS.

A small but strong line, like a mason's, or a fine fishing line, is now stretched between the two shears, resting in the fork, and making one turn around a short arm of each to prevent slipping, and when drawn tight it is fastened at each end to a peg, driven in the ground about five feet beyond the foot of the shears, and near the line of the ditch. The distance of the pegs to which the line is attached, from the foot of the shears, is a matter of importance, for the reason that, if they are nearer the foot of the shears than the height of the line above the ground, the strain on the line between the top of the shears and the peg will be greater than between the two shears, and the line is liable to be broken between the shears and the pegs, when subjected to the necessary tension to keep it straight. The smaller the line the better, provided it has the necessary strength, as the tendency to sag between the shears increases with the size of the line. As all lines will sag more or less, if the shears are several rods apart, it was found necessary to provide some simple and convenient means of

support to correct this defect. The most satisfactory device for this purpose is the "gauge stake," represented in fig. 32.

The vertical rod of hard wood, about one and one-fourth inches in diameter, and five feet, or more, in length (a long fork handle will answer), should have a sharp iron point, which is readily made from a piece of gas pipe, and an iron band around the upper end to prevent splitting, when it is driven into the ground. The horizontal arm, about two feet long, and two by two and one-half inches at the end through which the vertical rod passes, is tapered to three-fourths of an inch at the other end, to diminish its weight. A rivet, not shown in the cut, should be put through the base of this arm, back of the key which clamps it to the vertical rod. When the line is in place over the middle of the ditch, the rod of the gauge stake is driven near the margin of the ditch, and the horizontal arm is slid up under the line, until the sag is corrected, when it is secured in place with the key which clamps it to the rod. Two or three of these gauge stakes may be conveniently used, so that the shears can be placed farther apart. The relations of the line to the shears and pegs, and the use of the gauge-stakes, will readily be seen in fig. 33. The sole object in view is to fix the line above the grade of the drain, so that it is not likely to be displaced in laying the tiles, by means that will facilitate its removal and readjustment in an advanced position as the work progresses.

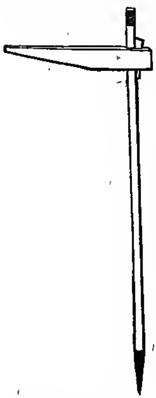


FIG. 32. GAUGE STAKE.

Other methods of supporting a line above the ditch to serve as a guide in laying tiles have been adopted. In laying sewer pipes, a wider and deeper ditch, (twelve

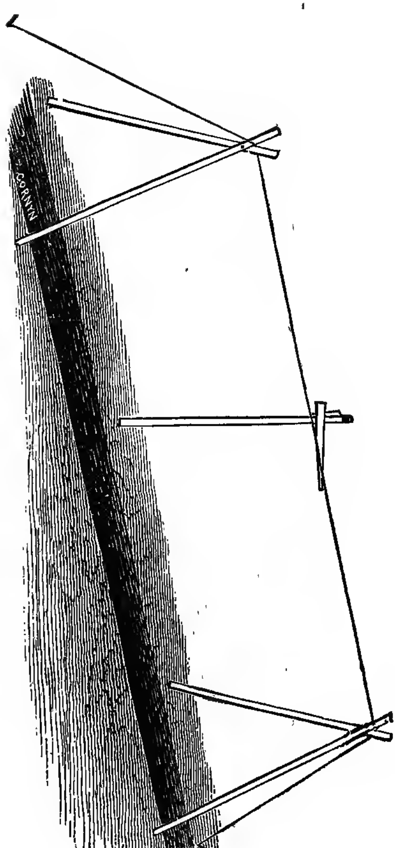


FIG. 33. LINE IN PLACE.

to fifteen feet deep), is usually required, than in ordinary drainage, and stakes are driven on each side of it at convenient intervals, and crossbars nailed to them to support the line, in the manner represented in fig. 34. In order to facilitate the adjustment of the crossbars, and the removal of the apparatus to a new position, Prof. R. C. Carpenter has planned a method of clamping the

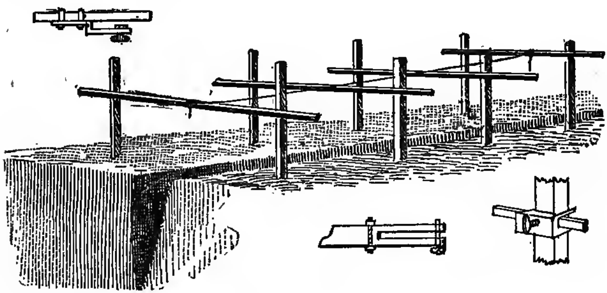


FIG. 34.

cross bars to the stakes, represented in the separate pieces in fig. 34, which will be found more convenient than to fasten them with nails.

In my own experience in fixing the line, the iron clamps, found in every hardware store, for fastening the corners of quilting frames, have been used for clamping the crossbars to the stakes, which, on the whole, is the cheapest and most satisfactory method I have tried. Where a wide ditch is required for laying the larger sizes of tiles, or sewer pipes, at depths exceeding four or five feet, this method of supporting the line has some advantages, but for laying tiles of six inches, or less, from four to five feet deep, as practiced in farm drainage, the method represented in fig. 33 has proved, in my experience, the most satisfactory, as it is much cheaper, more convenient, and less time is required in

moving and readjusting the line, while the apparatus, from the smaller number and bulk of the pieces, has decided advantages in portability.

In laying tiles four feet deep, seven feet has proved to be a convenient distance to place the line above the proposed grade, as a man can readily work under it when all but the last foot of excavation has been made. The position of the first tile at the outlet is the fixed point from which the grade must start, and the line is, accordingly, placed seven feet above its bed. The question will then arise as to the proper height of the line at the upper shears. If a depth of four feet has been decided upon, the line must, evidently, be placed three feet above the surface of the ground, but its position, when so fixed, should be tested, before any tiles are laid, to ascertain, beyond any doubt, that it represents a sufficient fall in the right direction. This precaution is absolutely necessary when the surface is nearly level and but a slight fall can be obtained. This verification may readily be made with a builders' spirit level, which can be obtained at any hardware store for one dollar, or less. When the line is in place the level held under it will show whether there is a good fall or not; but when the fall is slight a more exact method will be required.

To secure greater accuracy in the use of the level, provide two strips of board, two or three inches wide, and three or four feet long, with the lower ends sharpened and the tops square. Drive these stakes in the ground (so that they will stand firmly), about twenty inches apart, at a point nearly opposite the middle of the line, and about twenty feet from it. They should be so placed that the level resting on them is *parallel to the line*, and it can then be leveled by driving one or the other of the stakes, as may be required. When the level is accurately adjusted, stand back of it, two or three feet, and bring the eye in range with its upper edge and

the line over the ditch. A considerable length of the line will then be seen over the level, within the range of its ends, and its slope will be readily seen. If the fall is not sufficient, as the line is adjusted, its upper end must be raised, by bringing the arms of its shears nearer together, or, if the indicated fall is more than is required, the arms of the upper shears may be driven into the ground to lower the line at that point, and the desired grade may, in this way, be easily established. When laying tiles where there is but little fall, and strict accuracy is therefore required, it has been my practice to keep the level adjusted opposite the line, so that any accidental displacement could be detected and remedied without any delay in the progress of the work.

Measuring Rod.—When the line is properly adjusted, a light rod just seven feet long is used to measure, or gauge, from it, the grade on which the tiles are to be laid. As the excavation should not, in any case, be made below the desired grade, from the difficulty of filling the depression so that the tiles will not settle under the pressure upon them when the ditch is filled, the measuring rod should be frequently used to ascertain the exact amount of excavation to be made. By placing the lower end of the rod on the bottom of the ditch at any time, the distance of its top above the line will, of course, indicate the remaining depth to be dug. It is important, in using the measuring rod, that it is kept vertical when gauging the depth of the drain, and that the line is over the middle of the ditch, as an inclination of the rod in either direction will have the effect to shorten it. By holding the rod lightly between the thumb and fingers, near its upper end, it will then serve as a plumb, to indicate its proper position in measuring from the line.

When the tiles are laid to the upper shears, the line can be adjusted over the next section of the ditch in a

few minutes, the upper shears remaining in place, and the lower shears carried forward to the upper end of the line. This change in position, and readjustment of the line, can be made in less time than it takes to describe the process, and the level is then carried forward to a new position, to verify the results of the new adjustment.

A word of caution must here be given in regard to the use and care of the line. New lines, and those that have been wet, are liable to stretch, and constant attention is required, to detect and correct the first indications of sagging, and prevent a consequent sag in the drain. To keep the line dry, and avoid annoyance from its variations in length from the effects of moisture, it should be taken in at night, or whenever work is suspended, and readjusted when the work is resumed. If the tiles have not been laid to the upper shears, when work is suspended at any time, it will be best, in readjusting the line, to start from the last tile laid, by bringing the lower shears forward to it, when work is resumed, so that tiles may be laid the whole length of the line before it is again moved. These details may be looked upon as trifles hardly worth mentioning, but success in laying tiles will depend upon attention to many small matters, which, in the aggregate, are not inconsiderable.

How Tiles are Laid.—The ditch having been dug to within eight or ten inches of the bottom, and the line properly adjusted over the middle of the ditch, two men may begin the work of finishing the excavation and laying the tiles, which we will suppose are for a four-inch main, beginning at the outlet. A level-headed boy, or the proprietor as superintendent if he does not prefer to lay the tiles himself, will facilitate the work by managing the measuring rod, and performing any other service that may be required, from time to time, outside the ditch.

One of the men standing in the ditch, with his face towards the outlet, with the six-inch draining spade,

slices off the earth, or loosens it to nearly the required depth, moving backwards as the work progresses, while the tile-layer stands facing him and throws out the loose earth with a shovel scoop, or the draining scoop, fig. 30, as may be most convenient. When the excavation has been finished for a distance of three or four feet, the tile-layer planes a groove in the bottom of the ditch with the draining scoop, to the required grade, as gauged with the measuring rod, and lays two or three tiles in it with their ends closely in contact, and covers them with five or six inches of earth, on which he then stands,

FIG. 35.

packing it around the tiles as he proceeds with his work. The next section of the ditch is then prepared for three or four tiles by a repetition of the process of excavation —planing a groove for the tiles—laying them and covering with earth, to form a platform on which the tile layer advances, and the same routine is again repeated.

By following this system, it will be seen that the feet of the workmen are not within eight or ten inches

of the bottom of the ditch, the man with the draining spade standing on the earth to be excavated, and the tile layer on his underdrained platform, as represented in fig. 35, is exempt from the annoyances from mud and water that are usually associated with the work of draining. If the bottom of the ditch is soft, and water is running over it, the man with the draining spade will be standing in mud, which will interfere with his efficiency and the general progress of the work. This can, however, be obviated in a very simple way, that more than repays the extra trouble it involves. A one and one-half or two inch pine plank about six feet long, and a little narrower than the bottom of the ditch, is laid down for him to stand on. Near the upper end of the plank a hole should be bored, in which a small rope is tied, its free end being thrown over the edge of the ditch to keep it out of the mud. With this the plank can be pulled back from time to time, as may be required.

In the judicious application of this method the draining spade and the draining scoop are kept in supporting distance, each man being able to aid the other in any exigency that may arise, and their efficiency, through their combined efforts, will be materially increased. If the bottom of the ditch is hard, or small stones or pebbles interfere with the free use of the draining scoop, the draining spade is within reach, and its rounded point will readily chip out and loosen the obstructions. The man with the draining spade must constantly be on the lookout to facilitate the work of the tile layer, by making a straight trench, and rendering any assistance that is made possible from the advantages of his position. With the exercise of ordinary skill and judgment in making the last excavation, fragments of soil and mud may be prevented from entering the open mouth of the drain, by keeping the ditch clean, and finished to the grade, by the use of the draining

scoop, for a short distance above the last tile laid, and this will serve also as a starting point for the scoop in planing the groove for the next tiles.

Protection of the Joints.—Drains of moderate fall are liable to obstruction if silt is allowed to enter them, and the joints between the tiles should be sufficiently close to keep it out. To secure this essential condition, attention must be especially directed to the upper part of the joints, as silt from ordinary soils will readily work down into the drain through small fissures in the upper half of the tiles, while it would not pass through considerably wider ones on their under side. Close joints at the top of the tiles must, then, be looked upon as absolutely necessary, while, in the lower half of the joints, close approximations of the ends of the tiles are, of course, desirable, and care should be taken to secure them, yet they are not as imperatively required to insure the permanence of the drain.

Tight joints at the top of the old-fashioned sole, and horseshoe tiles, could seldom be made, and the defect was remedied by laying a piece of sod over the joint before covering the tiles with earth. Even the round tiles of a few years ago frequently had uneven ends, so that perfect joints could not readily be made, and a protection of sods, or other materials, was needed, to make a reliable drain. The labor involved in cutting and distributing sods along the line of the drain, was a serious objection to their use, and in many cases they could not, without great trouble, be obtained. The best and cheapest substitute for sods, all things considered, according to my experience, was found to be strips of tarred roofing paper, about two inches wide, and long enough to cover the upper half of the joints, as they were convenient to use, could be kept always ready when needed, and served the purpose admirably.

With greater care in the manufacture of tiles, arising from increased competition, and when the best qual-

ity of clay, free from pebbles, is used, these defects are not as common, but they have not entirely disappeared. When the ends of the tiles are square, and reasonably true, so that close fitting joints can be made by rotating the last tile in its bed, as it is laid, there is really no need of any protection as a general rule, as ordinary soils, when firmly packed over the tiles, will not work through into the drains. If the ends of the tiles, however, are not in contact at the top, and a space is left that will admit a thin knife-blade, they should be covered with strips of tarred paper, or some other material, and it may be well, as a matter of precaution, to cover all of the joints when laying tiles, if actual contact of their ends in the upper half of the joints cannot quite uniformly be secured. While tight joints need no protection, too much care cannot be exercised in thoroughly covering and protecting all imperfect joints.

Laterals and Junctions.—Main and sub-main drains should, if possible, be laid, as already suggested, at least their diameter lower than the branches, or laterals, which empty into them, so that the drains may run full without setting back water into its tributaries, and checking the flow of water in them. Laterals should, therefore, enter a main drain near its top, or crown, and at an angle that will favor the discharge of their water with the current towards the outlet. A discharge of water into a drain at right angles to its course will check its current, and if the drain is running full this will, in effect, diminish its capacity.

When the course of a lateral is nearly, or quite, at right angles to the main into which it is to empty, a change in its direction on a gradual curve, will be required just before it reaches the main, so that a junction may be made for its discharge in the general course of the current towards the outlet. If the main is low enough to allow it, a slight increase in the fall on this curve will be desirable.

Manufacturers of tiles now make *Y*, fig. 36, and *V*, fig. 37, junctions for tiles of all sizes, and curves, fig. 38, of different degrees of curvature, for changing the direction of drains.

When the mains are laid these junctions may be put in where the laterals are required, the end of the branch being closed with a flat stone, or piece of brick,

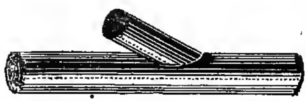


FIG. 36. *Y* JUNCTION.

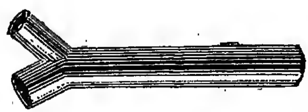


FIG. 37. *V* JUNCTION.

until needed. An accurate record of these junctions should be made on the map, so that they can easily be found when the laterals are to be laid. Their place in the field may also be marked with a stake, but this is liable to be displaced, and should not be the only record. Even with these aids in construction, it will, in most cases, be found necessary to cut tiles, more or less, to form perfect joints in making connection with them, and avoid abrupt angles in the drain.

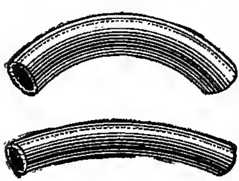


FIG. 38. CURVES.

Tile Picks.—The tools required for this purpose, and for cutting and fitting tiles in other places, are the hammer pick, fig. 39, or the hatchet pick, fig. 40. With a little practice tiles may be cut, and junctions readily made, with either of these tools. In my own practice, for several years, the hammer form has almost always been used, as, on the whole, the most convenient. These tools should be made of the best steel, and have a cold-chisel temper, in order to cut well burned tiles. The

head of the hammer pick may be about seven-eighths of an inch square at the largest point, and four and one-fourth inches long, or about the weight of a light riveting hammer, the sides and face being flat, with sharp angles all round. The point of both tools should terminate in an abrupt bevel, like the edge of a cold-chisel, as a slender point will break, and cannot be kept sharp. The "edge" of the hatchet pick should have a similar bevel, or it may be one-fourth of an inch wide and ground flat at right angles to its sides.

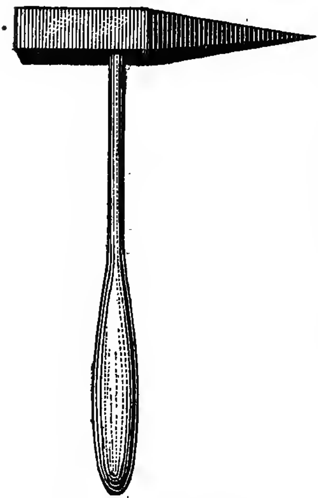


FIG. 39. HAMMER PICK.

To make a junction, pick a hole through the side of a tile from the main, with the point of one of these tools, and enlarge it in an oblong form, the width being about equal to the inside diameter of the tile which is to form the branch. The end of this branch tile is then beveled and hollowed out to fit the outside of the tile from the main at the proper angle. When a good fit is made by chipping with the point, or cutting with the sharp angles of the hammer or hatchet, as may be most convenient, place the branch in its proper position over the hole in the tile from the main, and by looking

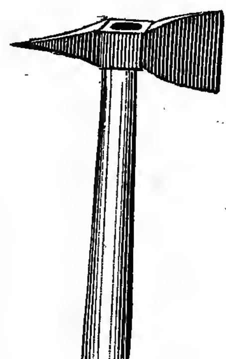


FIG. 40. HATCHET PICK.

through its bore the additional cutting or trimming of the hole in the main, that is required to allow a free discharge from the lateral, will readily be seen. When the fitting of the two tiles together is finished they are laid in position in the drain, and the earth packed around them to hold the branch in place.

To Lay the Laterals, begin at a junction laid in the main, and make a connection with its branch by cutting the ends of the first tiles more or less obliquely, to make good joints, and give the proper direction for the tiles to be laid. Care must be taken to secure a firm bed for these connections, by making as little excavation as possible to bring the tiles to their place, and in covering them the earth must be packed to prevent any displacement when the ditch is filled. The ditch for the laterals is dug, the shears and line adjusted, and the tiles laid, as described above in the case of the main drain, the lower shears being placed over the junction at the point where the true grade of the lateral begins. When the laterals are finished the ends of the last tiles should be carefully covered with a half brick, or a flat stone, to keep out silt.

When ready-made junctions cannot be obtained the mains may be laid without reference to the laterals, or junctions may be made with a tile pick for the laterals that are to be laid at the time, care being taken to prevent any displacement of the branch before the laterals are connected with it. After reaching a junction, it will be seen that two gangs of hands may be employed at the same time, if desirable, the one laying the continuation of the main, and the other laying the lateral.

After a main has been finished and a lateral is to be laid, at any time, where no junction has been provided, let the ditch for the lateral begin over the main, bearing in mind the curve required at the lower end of the lateral in making the connection, and uncover the tile in

which the junction is to be made. After removing the earth from its side towards the ditch as far as may be necessary, roll it out of its bed, pick a hole at the point previously marked for the branch, which is then fitted to form a junction. The tile taken from the main is then returned to its former place, the branch is secured in its proper position, and the connecting tiles are laid to the beginning of the straight course of the lateral, after which the work is carried on according to the regular routine. A change in direction, or a curve in a drain, may be made, by trimming the ends of the tiles to a slight angle and smoothing the surface to make a tight joint.

CHAPTER X.

Drains in Quicksand and Peat.

Beds, or pockets, of quicksand are frequently found within four feet of the surface, in many localities in the drift formation, and they have been looked upon as serious obstacles in draining, that could not be surmounted when tiles alone are used. Boards and foundations of stones to support the drain, or conduits of planks, and built-up drains of stones, were believed to be necessary, by writers who gave any attention to draining in quicksand,* and in late years collars are frequently mentioned as indispensable if tiles are used. These expensive methods, in connection with the popular notion that quicksand will work into a drain wherever water can enter, have tended to discourage attempts to drain land which might be made valuable by a comparatively mod-

*Henry Stephens, Manual of Pract. Drain., 3d ed., 1848, p. 14: Munn's Pract. Land Drainer, N. Y., 1855, p. 132. French, Farm Drainage, 1859, p. 314. Loudon, Encycl. of Agr'l, 6th ed., 1869, p. 702.

erate outlay under a more consistent system of management. Boards and stones should never be used in quicksand, as they serve no useful purpose, and materially increase the difficulties of construction; while collars only serve to hide imperfect joints, and are, therefore, a source of weakness in the finished drain. A careful consideration of the properties of quicksand, and its behavior under different conditions, will suggest the most available means of obviating the difficulties presented in its management.

What is known as quicksand, flowing-sand, or running-sand, is a fine-grained sand, without angles in its particles to increase friction, and sometimes mixed with fine clay, that is easily moved when saturated with water, and readily yields to intermittent pressure. It is freely transported by running water, but, when closely confined and kept in place, it resists continuous pressure, and when thoroughly drained it furnishes a stable foundation for tiles that are properly laid to drain it. If a pocket, or bed, of quicksand is met with in digging a ditch, and the level of the water table is above the sand, it offers no resistance to the hydrostatic pressure and runs into the ditch as fast as it is removed, keeping the level required to establish an equilibrium between its own weight and the pressure to which it is subjected. If the excavation is continued, under these conditions, the banks of the ditch are undermined and cave off, filling it with a mass of earth, which must be removed, and this process may be repeated, if further excavations are made. When the water has considerable head, as it will have, in a wet season, or in the case of springs, the sand will "boil up" into the ditch, filling it to a greater or less height, according to the head of water to which it is exposed.

These facts are suggestive, and of great practical significance. From its characteristic qualities, quick-

sand varies in its behavior with the conditions of its environment, and, in dealing with it, the conditions must be provided which increase its stability, and these may be formulated in the following rules for its successful management in draining: 1st. In land in which quicksands abound, drains should only be made in the summer, when the water table is at its lowest level. 2d. When quicksand is found in the bottom of the ditch it should not be disturbed until the tiles are ready to be laid. 3d. The mouth of the tile which has been laid into the edge of the quicksand should be covered with a sod, grass-side down, or some other form of screen, to keep sand from flowing into the drain, and work should be suspended until the water table is lowered to the level of the drain. 4th. The ditch should not be opened, to expose the quicksand, more than a rod or two in advance of the tile-laying. The pertinence of these rules will readily be seen from the fact, that in time of drouth, ditches are dug and tiles laid in fine sand, without any difficulty, when the same sand, if flooded, or saturated with water, would at once be recognized as a bad form of quicksand.

In my first experience with quicksand in draining, the attempt was made to follow the usual practice of curbing the sides of the ditch and proceeding at once with the tile-laying as rapidly as possible. The expense involved in this method, and the unsatisfactory results obtained, soon convinced me that it was better to wait for the water table to be lowered by the drain already laid, and this has proved to be the most economical and only satisfactory plan. It is certainly better to stop work for a few days, or a week, or more, if necessary, according to the extent of the quicksand, and the amount of water to be discharged, than to perform disagreeable labor under difficulties, without obtaining any equivalent in actual progress.

The dangers of obstruction from the sand entering the drain are not as imminent as at first sight might appear, if care is taken to place a sod over the end of the upper tile whenever work is suspended, and the drain has been laid on a true grade, with even a moderate fall, increasing towards the outlet. From the form of the channel in a round tile, quicksand is moved by a slight current, that would not affect coarser particles of angular sand, and if it enters the drain in but moderate amount it passes on and is discharged at the outlet. Where there are depressions in the line of the grade the sand will, undoubtedly, be deposited, and the importance of laying the tiles on a true grade, with a constant descent towards the outlet, must be manifest. With reasonable care in every step of the process of tile laying, it will not be difficult to prevent the sand from entering the drain in sufficient quantity to form an obstruction.

Tile Laying in Quicksand.—The water table having been lowered so that work can be resumed, the line is adjusted over the ditch, with the lower shears directly over the last tile laid. As sand only is to be excavated, scoops will alone be used. The tile layer, with a draining scoop (fig. 30), stands in the ditch on the earth covering the tiles already laid, and his assistant, if needed, with a shovel scoop, stands on the movable plank in the ditch, rather farther back than when using the draining spade. Walking or standing in the ditch without the protection of the plank to distribute a person's weight over a larger surface than the unprotected feet, should be strictly prohibited.

How to Use the Scoop.—The excavation for the tiles must now be made with great care, to prevent any unnecessary disturbance of the sand, and success will largely depend upon the manner in which the scoop is used, if there is water still running in the ditch. When the blade of the scoop is in the sand, if its handle is

depressed, the air cannot enter under its point, and sand will be forced up from below, or pressed in at the sides, to fill the space through which the point of the blade has moved, and when the scoopful of sand is lifted the disturbed sand from the sides of the drain will move in to fill its place. To prevent this unstable condition of the sand the blade of the scoop should be pressed into it with a firm and steady movement, and its heel gently raised to admit the air under it, when it can be raised with its load without causing an inrush of sand to fill the excavation. The aim should be to raise the load on the scoop without communicating any tremor or jar to the surrounding sand. Whether a groove will be left in the bottom of the ditch, or not, when a scoopful of sand is thrown out, will then depend upon the manner in which the work is performed. When an excavation is being made in quicksand, it is in unstable equilibrium, and any sudden jar or tremulous movement of anything in contact with it will set it in motion. For this reason the measuring rod must be used with care, its lower end barely touching the bottom of the groove when getting the gauge of the grade from the line over the ditch.

A bed having been made for two tiles, and the length of the blade of the scoop beyond, if possible, they are carefully laid, with particular attention to making tight joints, which are then covered with a thin piece of a firm sod, or a strip of tarred paper. If the sod extends beyond the sides of the tiles it will do no harm, but it should be put in place without any jar to disturb the sand. With the same precautions fine earth, free from lumps, should now be placed over the tiles to the depth of several inches. Moreover, in packing it, the pressure must be the same on each side of the tiles, but when the ditch is filled above the level of the wet sand it will be safe to walk or stand upon it, in the excavation and laying the tiles in the next section, but it

will be well to bear in mind the unstable character of the soil beneath.

In most cases tiles may be laid, in this way, through the partly drained quicksand, with satisfactory accuracy, without any serious difficulty, but sometimes an extra soft place may be found for a short distance, where the ditch passes over a copious spring, in which it may be necessary to lay sods to furnish a sufficient support for the tiles until they are covered with earth. In such an emergency the sods should be of nearly uniform thickness and cover the bottom of the ditch from side to side, after the excavation has been made as close to the desired grade as the conditions will permit. To lay a tile, in such cases, place it on the sod, and stand with one foot upon it to bring it to the grade, and make a joint with the preceding tile. If it settles too low, place thin sods under it until it is brought to the grade when bearing a man's weight, and cover the joint with a wide sod, and pack the earth on each side and over it when still under pressure. The measuring rod, to determine the proper grade, should be used from the top of the tile, the diameter of which should be marked on the upper end of the rod to gauge with the line. With sufficient care, and the exercise of a little ingenuity and judgment, such places may be bridged over with satisfactory results, and the drain kept to the required grade.

Several years after laying tiles in the manner described above, through an unusually bad bed of quicksand, the top of which was nearly two feet above the grade of the drain, the tiles were uncovered for a distance of between two and three rods, to ascertain whether any displacement had taken place when they were laid. The drain was found to be in perfect condition, and the tiles varied less than half an inch from a true grade, and the permanent character of the work was evident. In numerous similar cases drains are running well that

have been laid more than fifteen years, without any known instance of failure.

Tiles in Peat.—Tiles laid in peaty soils are much more liable to displacement than when well laid in quicksand, and care in laying them is necessary to secure a permanent drain. In draining marsh lands where the peat extends below the grade of the drains, it may not be advisable to lay tiles until the soil has been allowed to settle, after draining with open ditches. When tiles are laid in peat the excavation should never be made below the line of grade, from the difficulty of filling the depression, to secure a uniform grade in the drain when the ditches are filled. On account of the unstable character of peat as a foundation for a tile drain, three-inch laterals have been used, and they appear to have a number of advantages over smaller sizes.

Marsh soils, containing a large proportion of peat, become more compact when drained, thus diminishing the depth of soil above the drains. It is a common error, in draining swamps, to make the drains too shallow, and the subsequent shrinking, or settling of the soil, brings them still nearer the surface. If a suitable outlet can be secured, tiles in peaty soils should be laid, at least four feet deep, and it would be better to have that depth after the soil has settled. Marsh lands should be thoroughly drained, in order to give the best results, as they are naturally retentive of moisture, and, if they are saturated with water for a considerable time in a wet spring, their value during the following season will be very much impaired, through defective soil metabolism.

Most of the failures in draining marsh lands that have come under my observation are clearly attributable to insufficient drainage, and the flooding of the soil in wet seasons, or in wet spring months. The facts presented in chapter five, in regard to the capacity of drained soils to absorb and retain capillary water, and

the beneficial effects of deep and thorough drainage in times of drouth, must be sufficient to indicate the fallacies of the unfounded assumption, that there is danger of making marsh soils too dry by thorough draining. A deep range for root distribution is quite as important in peaty, as in upland soils, and shallow drainage is not a rational remedy for prospective drouths. Peaty soils, as a general rule, yield slowly to the ameliorating effects of draining, under the most favorable conditions, and the water table must be kept uniformly below the stratum of soil it is proposed to make available for growing crops, in order to obtain satisfactory results.

CHAPTER XI.

Outlets and Obstructions.

One of the essential conditions of an efficient drain, or system of drains, is a sufficient outlet for the discharge of the water brought to it without checking or retarding its current. When the outfall will permit, it may be advisable to lay the tiles deeper at the outlet, and for some distance up the main, to secure a better fall in the drains tributary to it, especially when the surface of the area to be drained is nearly level. Laterals discharging directly into an open ditch, or creek, are particularly liable to a displacement, or obstruction, of the tiles at the mouth of the drains, from various causes that need not be enumerated. Instead of these numerous outlets, that require constant attention to keep them in working order, it will be better to lay an intercepting main some distance back of the open ditch, or other water course, to collect and discharge the water at a single outlet which can be suitably protected. On

the whole, this will result in a saving of expense, and, what is quite as important, it will insure efficiency in the system of drainage.

Outlet of Drains.—The outlets of tile drains should be protected from the dangers of displacement by the action of frost, the washing of the banks where they come to the surface, and the treading of cattle, and provisions should be made to keep vermin from entering the drain to cause an obstruction. The best, and, in the long run, the cheapest, protection for the outlet, is a retaining wall of stones, laid in cement mortar, the foundation extending below the action of frost, and the top carried three feet, or more, above the drain, to support the earth covering its approach to the outlet. The tiles at the outlet should be well burned, and impervious to water, to prevent crumbling by frost, and the terminal tile, projecting several inches from the face of the retaining wall, should be a size larger than those above it, to provide room and opportunity for protection by a grating, or other device, to keep out vermin, without impeding the discharge from the drain. A length of glazed sewer pipe, a size larger than the drain, will form an efficient and convenient outlet, with advantages that will readily be recognized. A grating of some kind should be placed over the end of the drain, to keep out vermin, or a valve, placed obliquely at the end, or just within the last tile, so that it will open freely by the force of the current, and close as the flow of water diminishes, will serve the same purpose if properly adjusted. As the efficiency of the entire system of drainage depends upon a free discharge of water at the outlet, these precautions to prevent any displacement of the tiles, and to guard against possible causes of obstruction, cannot be considered as of minor importance.

The exercise of good judgment, and skill in engineering, may, in many cases, be required to make the

best location for the lower course of a main drain, and in deciding upon the most available outlet. When the natural surface drainage of a field is over lands of an adjoining owner, and a long line of drain would be required to follow the lowest line of descent, a short cut may sometimes be made by a deeply laid main, with a saving in expense, and at the same time an undesirable partnership interest in the drain may be avoided. In Mr. Woods' system of drainage, which has already been noticed, a considerable saving in the expense was effected, and the drain kept on his own land, by making a cut of more than twice the depth of the rest of the drain for the five-inch main, for several rods through a ridge, and a better fall, owing to the shorter distance, was likewise obtained. Depressions of the surface, or isolated basins, frequently occur, that may be drained by a deep cut for the main, when an outfall can be found within a reasonable distance. When the retentive soil of these basins rests upon a bed of sand or gravel, as is frequently the case, a well, sunk to the previous strata, may serve as an outlet into which the drains are made to empty, and when they are finished the well may be bridged over, just above the level of the tiles, and covered with soil, so that they will not interfere with the cultivation of the field.

Care of Drains.—Drains of round tiles laid on a true grade, with closely fitting joints, may be looked upon as permanent improvements, but at the same time, it is well to keep in mind the fact, that under certain conditions they are liable to obstructions, which should at once be removed, to avoid the risk of an increase of the difficulty and a complete stoppage of the drain. As these accidents seldom occur, they may be overlooked in their early stages, when most easily remedied, if frequent attention is not given to the drains to see that they are in working order.

Obstructions.—If the outlet is protected to prevent an invasion by vermin, and the tiles have been properly laid, the only causes of obstruction that require special atteution, are the stoppage of the drain by the roots of "water-loving trees," by deposits of oxide of iron, or from a displacement of the tiles by what is popularly called a "washout," when the drains are running full under a considerable head of water after an extraordinary rainfall.

Obstruction by Roots.—The roots of trees sometimes find their way into the tiles, even when close joints have been made, and the drain is, more or less, completely filled with a spongy mass of fine fibrous rootlets, through which the water cannot run. Elms and willows are the most common intruders, but the roots of the ash, the poplars and alders have been reported as causes of obstruction, and the list should, perhaps, be extended. Even the roots of farm crops have been known to cause an obstruction in tiles under favorable conditions. The roots of mangels have been found in tiles at a depth of three and one-half feet, and the roots of horse radish have been reported as causing a complete stoppage of tiles at a depth of seven feet.

On the other hand, drains have continued to work without obstruction in the vicinity of elms and willows, and farm crops of all kinds have been grown on drained land without any indication that their roots interfered with the integrity of the drains. The invasion of tiles by the roots of plants must, therefore, be determined by special conditions, that are not the necessary results of draining.

From a careful examination of the cases reported, in connection with my own observations, it appears to me evident that a perennial stream of water in the drain, and a prevailing drouth, are the essential conditions for the stoppage of tiles by the roots of plants, and I have

failed to find a single instance in which roots have stopped a drain that was dry for several weeks in the summer. When drains receive water from springs, so that they continue to run in time of severe drouth, roots, from a deficiency of moisture in the soil, enter the tiles for a more abundant supply. As the water in the drain carries in solution food materials, which are made available by the plants, the roots are rapidly developed, as they always are in good feeding grounds, and they may extend for some distance along the drain, until, by the increase in numbers, it is completely full. In dry weather in the summer the water table is usually considerably below the level of farm drains, so that they fail to run for several weeks in succession, and the roots of plants have no inducement to enter the drains. On the other hand, when the water table rises, so that the drains begin to run, roots have convenient supplies of water, without resorting to the abnormal method of entering the drains.

When drains have been stopped with roots, trees in the immediate vicinity have been cut down, as the supposed intruders, without remedying the evil, which has finally been traced to trees several hundred feet from the drain. The only remedy for this form of obstruction is the removal of the offending trees, and, where there are several growing in the vicinity, it may be difficult to decide which one is the exciting cause.

Washouts in Drains.—A common cause of obstruction, in drains that are carelessly made, is the displacement of the tiles by a "washout," when the fall has been diminished towards the outlet. The diminished fall involves a decrease in the velocity of the current, and when the tiles are running full, the capacity of the drain, in its lower course, is not sufficient to freely discharge the volume of water received from above. The influence of a diminished fall in retarding the flow

of water in a drain, will be sufficiently illustrated by a few figures from a table by Prof. R. C. Carpenter, of Cornell University.* A three-inch tile, with a fall of four inches in a rod, will discharge about the same amount of water as a four-inch tile, on a grade of one inch to the rod; and a four-inch tile, with a fall of five inches in a rod, will discharge about the same volume of water as a six-inch tile, with a fall of three-fourths of an inch in a rod.

The check given to the current by diminishing the fall is extended to the tiles higher up, and the water is set back in the drain, until it has sufficient head to force the water out at the joints of the tiles in the vicinity of the change in grade, and if it then finds its way under, or by the sides of, the tiles, they are finally undermined by the washing of the soil, until they settle and interrupt the continuity of the water way. The indications of the obstruction are the same as in the stoppage of the drain by other causes, and the surface soil over the drain may remain undisturbed.

The remedies for such accidents are obvious, and should not be overlooked when the drain is made. After extraordinary rains, the mains of farm drains will probably run full for several days, which will do no harm if the tiles have been laid with proper care, on *a true grade which is constantly increasing towards the outlet.* This should be the aim, in planning the drains, in all cases, but when it is necessary to diminish the rate of fall in the lower course of a main, a larger tile should be laid to give an increased capacity, with diminished velocity of the current.

When a rapid fall in a main is changed to a moderate one lower down in its course, a considerable enlargement of the drain may be necessary to secure a free discharge of the volume of water brought down by the

*Mich. Report of the State Bd. of Agr'l, 1886, p. 174.

more rapid current in the tiles above. From the facts presented it must be seen that a long main, even with moderate fall, and receiving branches throughout its course, should not be laid its entire length with tiles of the same size. If, for example, a six-inch main at the outlet is decided upon, as sufficient for the area to be drained, from the considerations presented in the preceding chapters, it may be diminished to five, and then four, and finally three inches, without loss of efficiency and with a considerable saving in the cost of construction. Good judgment in the application of correct principles will be required to make the changes in size at the proper place.

It is a common mistake to assume that tile-laying is simplified when there is a good fall, and that any one can lay tiles under such conditions. In laying tiles where there is a rapid fall, extraordinary care should be exercised in the alignment of the tiles, and in packing the earth closely around them to close all possible channels for the passage of water outside of the drain, and in connection with the precautions already suggested, the importance of close and well protected joints must be readily recognized.

Silt and Silt Basins.—From the imperfect joints that were of common occurrence, and almost unavoidable, when horseshoe and sole tiles were used, one of the most common causes of obstruction was sand, or, in general terms, silt, which found its way through the defective joints and accumulated in places to completely fill the tiles, and the recommendation was made to construct silt basins, at important points in the drain, as at junctions, to catch the sand and prevent its passing to the drain below. With the improved methods of laying round tiles, silt basins are not needed, and after the small amount of loose soil unavoidably admitted to the drain in the process of tile-laying has been discharged,

the appearance of silt in the drain must be considered as an evidence of faulty construction.

When two, or more, important sub-mains join the main at the same point, a convenient junction may be made by a well of bricks, in which the drains all terminate. These wells may be closed just above the tiles and covered with soil, or they may be continued to the surface by an eighteen or twenty-inch sewer pipe, the top being secured with a tight-fitting cover. A convenient means of inspecting the drains may, in this way, be provided, but it will seldom be advisable to make them, as they interfere, more or less, with the cultivation of the field.

Obstructions from Deposits of Oxide of Iron.—In the vicinity of ferruginous deposits in the soil, drains are liable to obstruction from an accumulation of oxide of iron, especially near the outlet. "Carbonate of iron is the salt contained in most ferruginous springs, in which it is held in solution by free carbonic acid; it is rarely present in a larger quantity than one grain per pint. Mere exposure to air causes its separation; the acid escapes, oxygen is absorbed, and hydrated peroxide of iron, mixed with a small quantity of organic matter, subsides, forming the ochry deposits so usual around chalybeate springs."*

A rapid fall in the main at the outlet will diminish the tendency to these deposits within the drain, but the best remedy, on the whole, is a well, as described above, on the line of the main, some distance from the outlet, so that the drain can be conveniently flushed, from time to time, by a piece of board placed over the outgoing tile, until the water rises in the well above the tiles, when it is suddenly allowed to escape, and scour the drain below by the force and volume of the current.

* Miller's Elements of Chemistry, vol. 2, p. 523.

Indications and Location of Obstructions.—When an obstruction occurs in the course of a drain, the current below it is checked, but may not be entirely interrupted, water is dammed back in the tiles higher up, and the soil is, more or less, saturated with water. The crop, growing in the vicinity, often furnishes the first indications of insufficient drainage, especially in wet seasons, or in time of drouth following a wet spring. It is frequently difficult to determine definitely the seat of the obstruction, but attention to the behavior of water in the soil will materially aid in the solution of the problem. Where there is a rapid fall in the drain, the water in the soil will percolate down along the course of the drain, and the wettest place may be some distance below the obstruction. But when the fall is slight the local indications at any given point are not likely to be as marked, and the obstruction may be below the greatest accumulation of the more widely diffused water in the soil.

After a careful examination of all the conditions, to locate the fault approximately, trial pits may be dug on the line of the drain, at intervals, as determined by the indications. If the pit is higher up the drain than the point of obstruction, the soil will be wet before the tiles are reached, and another pit must be dug lower down the line of the drain. When the obstruction is above the pit, water will not stand in the excavation over the tiles. It will seldom be necessary to dig down and uncover the tiles, in order to determine with certainty that the place of obstruction is between two of the trial pits, and by continuing the same method on a definite plan its exact location may be readily ascertained. Several lengths of tiles must then be uncovered, so that one of them just below the obstruction can be taken out and the obstacle removed. If the stoppage of the drain is complete, care must be taken to prevent the cause of the

obstruction from being carried, by the rush of water, to the drain below.

Empirical rules cannot, however, be formulated to meet all possible emergencies. In locating and removing obstructions in drains, as well as in drainage construction, an accurate knowledge of the general principles involved in the process will be found the best guide in practice, as the means adopted and applied can then be adapted to the constantly varying conditions presented in the field. Experience, under imperfect methods, without the guidance of sound principles, may prove to be an expensive teacher. Empirical precepts, and routine systems of practice, may be followed with fairly satisfactory results under certain conditions, which may, perhaps, be present in a majority of cases, but when any new factor is introduced to complicate the situation, they fail to meet the requirements of the changed conditions.

In the application of general principles, as guides in practice, the end to be gained is kept prominently in view, and the means of attaining it will be readily suggested by the various exigencies that may arise. An intelligent conformity to the laws that govern nature's operations, is essential to success, in its widest signification, in the business of farming, which deals with the most complex phenomena, under variable and constantly changing conditions.

INDEX.

Absorption of moisture by soils,........................88
Adjustment of line,.............162
Advantages of draining,.........71
Agriculture, how improved,......1
Anderson, Dr. James, on draining,...................104
Animals, source of energy of,...........................31
Aqueous vapor and radiant heat,.....................67, 89
Aqueous vapor of atmosphere,...68
Atmosphere, composition of,....13
Atmosphere, carbonic acid of,...........................5
Atmospheric nitrogen,...........13
Atmospheric moisture absorbed by soils,.........88, 89
Atmospheric moisture and conservation of energy,....90
Atmospheric moisture and frosts,.......................68
Atmospheric moisture and radiant heat,...............66
Bare soil, evaporation from, ...48, 51, 57
Barnyard manure and drainage,.........................83
Barnyard manure and microbes, ...11
Barnyard manure and soil moisture,..................82
Behavior of drainage water in soils,......................25
Biological factors in soil metabolism, ...10, 21
Blith, on draining,...............102
Boning rods,......................158
Buchanan's improvements in draining,................106
Business methods,......... 1
Capacity of drains,.........144, 147
Capacity of soils for holding water,...................78, 80
Capacity of soils for heat,........65
Capillarity of soils,............8, 76
Capillary water in soils,.24, 75, 144
Carbon, how appropriated by plants,.................3, 5
Carbonic acid of atmosphere,.....5
Care of drains,..................186
Cato on draining.................97
Central Park drainage,.........146
Cereals benefited by nitrogenous manures,........ ..13
Chemical changes in soils,.......10
Chlorophyll, use of,...............5
Circulation of soil water,........62
Climate affecting drainage and evaporation,..........51
Coal, value of, in evaporating water,.......................59
Collars for tiles,.................152
Columella on draining,.. 99
Compensations of nature,........69
Condensation of moisture liberates heat,..............91
Conditions of plant growth, ...4, 8, 9, 23
Conservation of energy,.........26
Constructive metabolism,.......28
Corn, variations in yield,........95
Corn, water exhaled by crop of,..........................7, 60
Cost of draining tools,..........160
Covered drains, antiquity of,....99
Covering of tiles,...........113, 143
Crop statistics of good and bad seasons,...............94
Curves in drains, how made,...174
Dalton's drain gauge,............35
Deanston system of draining,...........................106
Deanston system improved by Parkes,.................112
Deep draining cheapest,........114
Depth of drains,..............98, 132
Depth of roots,.................9, 72
Depth of soils,....................25
Dew and frost,....................69
Dickinson's drainage experiments,.......................36
Direction of drains,.............130
Discharge by Central Park drains,.....................146
Discharge by drains after rains,........................145
Discovery and invention, progress of,.................96
Distance between drains,.......133
Ditches for tile drains,..........161
Drainage and drouths,...........74
Drainage and evaporation,......56
Drainage and rainfall,.......35, 155
Drainage diminished by vegetation,......................44
Drainage experiments by Dr. John Dalton,...............35
Drainage experiments by Mr. John Dickinson,...........35

Drainage experiments by Mr. John Evans,............44
Drainage experiments by Mr. C. Greaves,.............42
Drainage experiments at Geneva, N. Y.,..............54
Drainage experiments at Rothamsted,................45
Drainage water in soils,..........24
Drained soils, reservoirs for storing water,...............93
Drained soils utilize energy and moisture,...............67
Drain gauges by Dalton,.........35
Drain gauges at Geneva,.........54
Drain gauges at Rothamsted,....45
Draining, advantages of,........71
Draining bricks and tiles, old forms,..................117
Draining by the ancients,.... ...97
Draining, indirect advantages of,....................72
Draining level, how to use,....167
Draining marsh lands,..........183
Draining scoops,.................159
Draining spades,.................124
Draining tiles, evolution of,....116
Draining tools,..................159
Draining tools, obsolete forms of,..................127
Drains, care of,..................186
Drains, depth of,................132
Drains, direction of,............130
Drains, distance between,......133
Drains, how rainfall reaches,...142
Drains in quicksand and peat,......................177
Drains laid from outlet,.........137
Drains, location and plans of, ...130
Drains, mapping of,............135
Drains on farm of A. F. Wood, ...150
Drouths and drainage,..........74
Elkington's system of draining,.........................104
Empirical rules, value of,.......193
Energy and drainage water,.....63
Energy and soil temperatures, ...62
Energy conserved by draining,.........................73
Energy defined,..................26
Energy derived from the sun,....31
Energy expended in growth of plants and animals,.....58
Energy, farmers interest in,.....31
Energy, how measured,.........27
Energy in evaporation,..........58
Energy in exhalation by plants, ...60
Energy in physiology,...........28
Energy, law of its conservation,.......................27
Energy of the universe,.........31
Energy required by animals,....31
Energy required by plants,......61
Energy, stored or potential,..29, 30
Energy, transformations of, ...30, 31, 32
Evans' drainage experiments,.......................44
Evaporation and drainage,......35
Evaporation, energy expended in,.......................59
Evaporation from a bare soil,..........................48
Evaporation from a water surface,......................52
Evaporation of soil water,.......58
Evaporation, variations in,......50
Evolution of drain tiles,.........116
Exhalation by plants,.............6
Exhalation per acre by wheat,.......................7
Exhalation per acre by corn,.....7
Exhaustion of soils,.............12
Expenditures of energy,.........58
Extraordinary rainfalls,....152, 156
Fallow soils, loss of fertility in,...........................12
Farm crops, depth of roots of,.........................9, 72
Farm drains, plans and location of,.......................130
Farmers dealing with energy,.......................31
Fermentation,....................10
Fertility and chemical composition of soils,............18
Fertility and plant food,........23
Fertility, purchased,.............1
Field crops, range of roots of,...........................72
Field crops, water exhaled by,............................7
Flat bottomed tiles,.............119
Food of farm crops,...........8, 11
Four feet a desirable depth of drains,..................133
Frequent drain system,.........107
Frost and atmospheric vapor,.........................68
Frost and dew,...................69
Gauge stakes,....................164
Gauging the grade,..............168
General principles,................1
Geneva, drainage and evaporation, ...54
Germination of seeds, temperature required,...........5
Grade fixed by a line,...........158
Grating for outlets,.............185
Greaves' drainage experiments,.....................42
Growing crops, energy expended in,...................61
Growing crops, fertility conserved by,..................11
Guides in practice,..............193
Hammer for cutting tiles,.......175
Hatchet for cutting tiles,.......175
Heat, conserved by atmospheric vapor,...........68, 69
Heat, mechanical equivalent of,.....................27

Heat of decaying substances,....30
Heat units,.........................27
Heavy draining scoops,..........129
Hellriegel's experiments,.........14
High lands drained by Mr. Buchanan,.................106
High lands drained by Smith of Deanston,...............108
History of draining,..............96
Horse shoe tiles and soles,......118
How does the rainfall reach the drains,.................142
How does water enter tile drains,.......................140
How to make tile drains,...157, 169
Hydrostatic water in soils,......24
Hygroscopic water of soils,......24
Hygroscopic water used by plants,.......................91
Implements for tile draining,.........................123
Improved farm practice,..........1
Improved methods of draining by Mr. Parkes,.........115
Improved methods of draining by the Author,........158
Increasing fall of main towards the outlet,............132
Increasing size of main towards the outlet,............190
Indian corn, exhalation of water by,.................7, 60
Indian corn, losses from bad seasons,.....................95
Indications of deficient drainage,.........................70
Indications of obstructions in drains,.................192
Inherited feeding habits of plants,......................22
Inoculation of soils with microbes,......................18
Irrigation in drouths,............97
Johnston of Geneva, N. Y.,.....116
Joints of drains, how made,....175
Joints of drains, protection of,.........................172
Junctions of laterals,............173
Kedzie's observations on evaporation,..................54
Kedzie's soil experiments,.......77
Kinetic energy,...................30
Laterals and junctions,.........173
Laterals, how laid,..............176
Laws of life,.......................2
Laying tiles,.....................169
Leguminous crops and nitrogenous manures,............13
Leguminous crops and root nodules,.....................14
Level for draining,..............167
Life a factor in farm economy,.........................2
Line, care of,....................169
Line, how adjusted,.............162
Line in place,....................165
Line to determine grade of tiles,......................158
Living organisms, requirements of,......................4
Living organisms, role of,.......10
Locating and mapping drains,..135
Locating obstructions in drains,.......................192
Location and plans of farm drains,.......................130
Losses from bad seasons,........95
Loss of fertility in fallows,......12
Lupines in sterile quartz sand,.........................20
Lupines, Rothamsted experiments with,.................15
Main drains,.....................131
Main drains, fall increased towards outlet............189
Main drains, size increased towards outlet,............190
Maison Rustique,................100
Manures and soil moisture,.....82
Manures rotting of,..............11
Manures conserved by growing crops,..................11
Map of drains, how made,......135
Marsh soils, draining in,........183
Maximum discharge of drains,.156
Measuring rod,...................168
Mechanical equivalent of heat,..........................27
Metabolism defined,..............10
Metabolism of soils and drainage,...............10, 73
Michigan, evaporation in,.......54
Michigan rainfall,...............151
Michigan soils, capillarity of,...76
Microbes and manures,..........11
Microbes and mineral soil constituents,...............21
Microbes and nitrogen supplies of plant food,.........12
Microbes of nitrification,........12
Microbes, work of,...........11, 21
Micro-organisms and manures,...........................11
Micro-organisms of soils,........11
Miles' draining scoop,..........126
Miles' improved methods of draining,...................158
Moisture in air dried soils,......92
Moisture in cropped and uncropped land,...............78
Moisture in soil required by plants,........................6
Nature's compensations,.........69
Nitric acid as plant food,.........12
Nitrification influenced by temperature,..............12
Nitrification microbes,...........12
Nitrification of soils,.............12
Nitrogen, as manure,..........4, 12
Nitrogen, atmospheric supplies of,.......................13
Nitrogen of leguminous crops,...13
Nitrogen of organic substances and microbes,..........12
Nitrogen conserved by growing crops,...................11

Obsolete draining tools,........127
Obstructions,......................187
Obstructions from oxide of iron,,.......................191
Obstructions from roots of plants,......................187
Obstructions, how detected,....192
Obstructions, how removed,...192
Optimum temperature for plants,.........................5
Organic substances as plant food,..........................11
Outlets and obstructions,.......184
Outlets, protection of,..........185
Oval sole tiles,...................121
Oxygen required by plants,.....72
Parkes' experiments and improvements in draining, 64, 112
Palladius on draining,...........99
Peas, in sterile quartz sand,.. ..17
Peas, Rothamsted experiments with,.................15
Peat, laying tiles in,..............183
Philosophy of draining by Parkes,.....................113
Philosophy of farm draining,.....2
Physical changes in soils,.......10
Physiological laws,...............2
Physiology of plants,.............3
Pipe drains before the present century,................102
Pipe tiles recommended,.......112
Plank in ditch to avoid mud,...171
Plant food and fertility,.........23
Plant food, organic substances as,.................11
Plant food prepared by microbes,.. 21
Plant growth and soil evaporation,.................. ..62
Plant growth and soil metabolism,......................10
Plant growth, conditions of, ...4, 8, 9, 23
Plant physiology,..................3
Pliny on draining,................99
Plotting of drains,...............137
Plow in ditches,..................162
Potential or stored energy,......30
Principles of agriculture,.........2
Principles of drainage,.........153
Profitable crop growing,..........2
Progress of discovery and invention,............., ...96
Protection of joints,.............172
Protection of outlets,...........185
Pull draining scoop,............125
Push draining scoop,............126
Pull and push scoop,.......126, 160
Putrefaction caused by microbes,.........................10
Quality of tiles...................140
Quicksand, how to manage,....179
Quicksand, laying tiles in,.....181
Quicksand, use of scoop in,.....180
Radiant heat and atmospheric moisture,............66
Radiant heat and soil moisture,..........................89
Rainfall affecting water table,........................25
Rainfall and drainage, variations in,..................38
Rainfall, evaporation and drainage,...................35
Rainfall in Michigan,...........151
Rainfall retained by drained soil,........................154
Rainfalls, extraordinary,..152, 156
Range of roots of farm crops, ...9, 72, 133
Retentive soils, advantages of draining,..............70, 71
Root development and drainage,..........................72
Root distribution,.................8
Root fibrils,.......................9
Root nodules and nitrogen supply,.......................14
Roots in tile drains,............187
Roots of plants, action of on soils,.........................21
Roots, range in depth,....9, 72, 133
Roots, use of,.......................8
Rothamsted drainage experiments,........................45
Rothamsted experiments 1888-'89,........................15
Round tiles,.......................123
Round tiles, advantages of,....139
Sachs' exp. with hygroscopic moisture,..................91
Sag of line, how prevented,....164
Sand and turfed soil drainage,..........................42
Schloesing and Muntz, microbes of nitrification,.....12
Schubler's soil experiments,....66
Science in farm economy,........2
Scoops for draining,....125, 126, 159
Season, influence on food supply of crops,............23
Seasons and crop statistics,.....94
Seeds, germination of, temperature,.......................5
Selective power of plants,.......22
Shears for support of line,......163
Silt and silt basins,............190
Size and quality of tiles,.......139
Size of mains,...................149
Size of tiles,.....................148
Smith of Deanston, improved system of,.............106
Smith of Deanston system a rediscovery,............111
Smith of Deanston, the pioneer advocate of draining high lands,..........108
Sods to protect joints,..........172
Soil conditions of plant growth,...................3, 9
Soil evaporation,...............56, 58
Soil exhaustion,..................12
Soil metabolism,..................10
Soil metabolism and drainage,..73

Soil moisture,....................7, 78
Soil moisture and manures,.....82
Soil moisture and radiant heat,........................89
Soil moisture condensed from atmosphere,. 89
Soil temperatures,.........26, 68, 69
Soil temperatures and energy,........................62
Soils, available depth of,........25
Soils, capillary capacity of,....144
Soils, how warmed,...........68, 69
Soils, moisture in cropped and uncropped,.............78
Soils seeded with microbes,.....18
Spades for draining,............124
Spirit level, use of,..............167
Springs, perennial,.............187
Standing in ditch,...............171
Stephens' Book of the Farm,...122
Stephens' Manual of Draining,.123
Stoppage of drains,.............184
Stored or potential energy,..29, 30
Struggle for existence,..........11
Summer and winter drainage,........................40
Summer drainage slight,........47
Summer fallows,.................12
Sun's energy,....................33
Survival of the fittest,...........11
System of drainage, map of,....134
Table 1, Water in soil and yield of crops,...............7
Table 2, Plants in sterile soils,........................16
Table 3, Dickinson's drainage exp. monthly averages,........................36
Table 4, Dickinson's drainage exp. annual variations,........................37
Table 5, Dickinson's drainage exp. for each month,...39
Table 6, Dickinson's drainage exp. half-yearly averages,...................41
Table 7, Mr. Greaves' drainage experiments, ...42
Table 8, Rothamsted drainage, monthly averages,....46
Table 9, Rothamsted drainage, annual and semi-annual,.....................49
Table 10, Rainfall and evaporation, Syracuse and Ogdensburg, N. Y.,.........53
Table 11, Rainfall and drainage, Geneva, N. Y.,.........54
Table 12, Schubler's capacity of soils for heat,............66
Table 13, Schubler's capillary soil water,............75
Table 14, Rothamsted, wheat on drained land, yield,.....79
Table 15, Rothamsted, summer and winter soil water,.......................81
Table 16, Rothamsted summer and winter, tons of water per acre,............84
Table 17, Rothamsted soil water in fallow and barley land, percentages,........................86
Table 18, Rothamsted soil water in fallow and barley land, tons per acre, 87
Table 19, Atmospheric vapor absorbed by soils,.........88
Table 20, Soil water used by tobacco plant,......... 93
Table 21, Cost of draining at different depths, Parkes,..114
Table 22, Central Park drainage after rains,............146
Table 23, Central Park drainage maximum discharge,.147
Table 24, Relations of drainage to rainfall, averages,.155
Tarred paper to cover joints,...172
Temperature of soils, lowered by evaporation,.........64
Temperature of soils, required by plants,................4
Temperatures of soils, vapor of atmosphere influencing,.....................68, 69
Tile drain ditches, how made,..161
Tile draining implements,..123-129
Tile drains, construction of,....157
Tile drains, how covered,.......143
Tile drains, how water enters, ...140
Tile hammer,...................175
Tile laying, begin at the outlet,.....................137
Tile laying in quicksand,.......180
Tile laying, tools required,.....159
Tile pick for cutting,............175
Tiles, covered with clay,...113, 143
Tiles, cutting and fitting joints of,..................175
Tiles, how laid,..................169
Tiles in peat,........... 183
Tiles, quality and size of,.......139
Tiles, size of,.....................148
Tools required,...................159
Transformation of energy, 30, 31, 32
Turfed soils, evaporation from,.....................43, 44
Unit of heat for measuring energy,.....................27
Unit of work,.....................27
United States, climate in,.......51
Universe, energy of,.............31
Vapor, atmospheric, and frosts,....................68, 69
Varro on draining,...............98
Variations in drainage and rainfall,....................38
Vegetation diminishes drainage, ...44
Vetches in sterile soils, ...19
Vetches, Rothamsted experiments with, ...15

Waring's Central Park drainage,...146
Waring's draining tools,...128
Washout in drains,...188
Water and soil temperatures, 26, 59
Water, circulation of, in growing crops,...6, 62
Water culture experiments,...22
Water, energy required to evaporate,...61
Water exhaled by corn,...7, 60
Water exhaled by plants,...6
Water exhaled by wheat,...7
Water, how it enters drains,...140
Water in soils, forms of,...24
Water required by growing plants, ...
Water stored by drained soils, ...93
Water table,...24
Water table after rains,...143
Wells in drains,...191
Wet soils not readily warmed,...64
Wheat, water exhaled by,...7
Winter and summer drainage,...40
Winter drainage in excess of rainfall,...47
Wood's farm drains, ...150
Work in the trench,...170
Yeast, an alcholic ferment,...11
Yield of crops and soil moisture,...7

Mushrooms. How to Grow Them.

For home use fresh Mushrooms are a delicious, highly nutritious and wholesome delicacy; and for market they are less bulky than eggs, and, when properly handled, no crop is more remunerative. Anyone who has an ordinary house cellar, woodshed, or barn can grow Mushrooms. This is the most practical work on the subject ever written, and the only book on growing Mushrooms ever published in America. The whole subject is treated in detail, minutely and plainly, as only a practical man, actively engaged in Mushroom growing, can handle it. The author describes how he himself grows Mushrooms, and how they are grown for profit by the leading market gardeners, and for home use by the most successful private growers. The book is amply and pointedly illustrated, with engravings drawn from nature expressly for this work. By Wm. Falconer. Is nicely printed and bound in cloth. Price, post-paid............ 1.50

Allen's New American Farm Book.

The very best work on the subject; comprising all that can be condensed into an available volume. Originally by Richard L. Allen. Revised and greatly enlarged by Lewis F. Allen. Cloth, 12mo... 2.50

Henderson's Gardening for Profit.

By Peter Henderson. New edition. Entirely rewritten and greatly enlarged. The standard work on Market and Family Gardening. The successful experience of the author for more than thirty years, and his willingness to tell, as he does in this work, the secret of his success for the benefit of others, enables him to give most valuable information. The book is profusely illustrated. Cloth, 12mo... 2.00

Fuller's Practical Forestry.

A Treatise on the Propagation, Planting, and Cultivation, with a description and the botanical and proper names of all the indigenous trees of the United States, both Evergreen and Deciduous, with Notes on a large number of the most valuable Exotic Species. By Andrew S. Fuller, author of "Grape Culturist," "Small Fruit Culturist," etc. 1.50

The Dairyman's Manual.

By Henry Stewart, author of "The Shepherd's Manual," "Irrigation," etc. A useful and practical work by a writer who is well known as thoroughly familiar with the subject of which he writes. Cloth, 12mo............ 2.00

Truck Farming at the South.

A work giving the experience of a successful grower of vegetables or "grain truck" for Northern markets. Essential to any one who contemplates entering this promising field of Agriculture. By A. Oemler, of Georgia. Illustrated. Cloth, 12mo............ 1.50

Harris on the Pig.

New edition. Revised and enlarged by the author. The points of the various English and American breeds are thoroughly discussed, and the great advantage of using thoroughbred males clearly shown. The work is equally valuable to the farmer who keeps but few pigs, and to the breeder on an extensive scale. By Joseph Harris. Illustrated. Cloth, 12mo............ 1.50

Jones's Peanut Plant—Its Cultivation and Uses.

A practical Book, instructing the beginner how to raise good crops of Peanuts. By B. W. Jones, Surry Co., Va. Paper Cover,.... .50

Barry's Fruit Garden.

By P. Barry. A standard work on fruit and fruit-trees; the author having had over thirty years' practical experience at the head of one of the largest nurseries in this country. New edition, revised up to date. Invaluable to all fruit-growers. Illustrated. Cloth, 12mo. 2.00

The Propagation of Plants.

By Andrew S. Fuller. Illustrated with numerous engravings. An eminently practical and useful work. Describing the process of hybridizing and crossing species and varieties, and also the many different modes by which cultivated plants may be propagated and multiplied. Cloth, 12mo 1.50

Stewart's Shepherd's Manual.

A Valuable Practical Treatise on the Sheep, for American farmers and sheep growers. It is so plain that a farmer, or a farmer's son, who has never kept a sheep, may learn from its pages how to manage a flock successfully, and yet so complete that even the experienced shepherd may gather many suggestions from it. The results of personal experience of some years with the characters of the various modern breeds of sheep, and the sheep-raising capabilities of many portions of our extensive territory and that of Canada—and the careful study of the diseases to which our sheep are chiefly subject, with those by which they may eventually be afflicted through unforeseen accidents—as well as the methods of management called for under our circumstances, are here gathered. By Henry Stewart. Illustrated. Cloth, 12mo. .. 1.50

Allen's American Cattle.

Their History, Breeding, and Management. By Lewis F. Allen. This Book will be considered indispensable by every breeder of live stock. The large experience of the author in improving the character of American herds adds to the weight of his observations, and has enabled him to produce a work which will at once make good his claims as a standard authority on the subject. New and revised edition. Illustrated. Cloth, 12mo 2 50

Fuller's Grape Culturist.

By. A. S. Fuller. This is one of the very best of works on the culture of the hardy grapes, with full directions for all departments of propagation, culture, etc., with 150 excellent engravings, illustrating planting, training, grafting, etc. Cloth, 12mo 1.50

White's Cranberry Culture.

Contents:—Natural History.—History of Cultivation.—Choice of Location.—Preparing the Ground.—Planting the Vines.—Management of Meadows.—Flooding—Enemies and Difficulties Overcome.—Picking.—Keeping.—Profit and Loss.—Letters from Practical Growers.—Insects Injurious to the Cranberry. By Joseph J. White. A practical grower. Illustrated. Cloth, 12mo. New and revised edition. 1.25

Herbert's Hints to Horse-Keepers.

This is one of the best and most popular works on the Horse in this country. A Complete Manual for Horsemen, embracing: How to Breed a Horse; How to Buy a Horse; How to Break a Horse; How to Use a Horse; How to Feed a Horse; How to Physic a Horse (Allopathy or Homœopathy); How to Groom a Horse; How to Drive a Horse; How to Ride a Horse, etc. By the late Henry William Herbert (Frank Forester). Beautifully Illustrated. Cloth, 12mo... 1.75

Henderson's Practical Floriculture.

By Peter Henderson. A guide to the successful propagation and cultivation of florists' plants. The work is not one for florists and gardeners only, but the amateur's wants are constantly kept in mind, and we have a very complete treatise on the cultivation of flowers under glass, or in the open air, suited to those who grow flowers for pleasure as well as those who make them a matter of trade. The work is characterized by the same radical common sense that marked the author's "Gardening for Profit," and it holds a high place in the estimation of lovers of agriculture. Beautifully illustrated. New and enlarged edition. Cloth, 12mo.................................. 1.50

Harris's Talks on Manures.

By Joseph Harris, M. S., author of "Walks and Talks on the Farm," "Harris on the Pig." etc. Revised and enlarged by the author. A series of familiar and practical talks between the author and the deacon, the doctor, and other neighbors, on the whole subject of manures and fertilizers; including a chapter specially written for it by Sir John Bennet Lawes, of Rothamsted, England. Cloth, 12mo........... 1.75

Waring's Draining for Profit and Draining for Health.

This book is a very complete and practical treatise, the directions in which are plain, and easily followed. The subject of thorough farm drainage is discussed in all its bearings, and also that more extensive land drainage by which the sanitary condition of any district may be greatly improved, even to the banishment of fever and ague, typhoid and malarious fever. By Geo. E. Waring, Jr Illustrated, Cloth 12mo. 1.50

The Practical Rabbit-Keeper.

By Cuniculus. Illustrated. A comprehensive work on keeping and raising Rabbits for pleasure as well as for profit. The book is abundantly illustrated with all the various Courts, Warrens, Hutches, Fencing, etc., and also with excellent portraits of the most important species of rabbits throughout the world. 12mo................ 1.50

Quinby's New Bee-Keeping.

The Mysteries of Bee-keeping Explained. Combining the results of Fifty Years' Experience, with the latest discoveries and inventions, and presenting the most approved methods, forming a complete work. Cloth, 12mo 1.50

Profits in Poultry.

Useful and Ornamental Breeds and their Profitable Management. This excellent work contains the combined experience of a number of practical men in all departments of poultry raising. It is profusely illustrated and forms an unique and important addition to our poultry literature. Cloth, 12mo.. 1.00

Barn Plans and Outbuildings.

Two Hundred and Fifty-seven Illustrations. A most Valuable Work, full of Ideas, Hints, Suggestions, Plans, etc., for the Construction of Barns and Outbuildings, by Practical writers. Chapters are devoted, among other subjects, to the Economic Erection and Use of Barns. Grain Barns, House Barns, Cattle Barns, Sheep Barns, Corn Houses, Smoke Houses, Ice Houses, Pig Pens, Granaries, etc. There are likewise chapters upon Bird Houses, Dog Houses, Tool Sheds, Ventilators, Roofs and Roofing, Doors and Fastenings, Work Shops, Poultry Houses, Manure Sheds, Barn Yards, Root Pits, etc. Recently published. Cloth, 12mo.. 1.50

Parsons on the Rose.

By Samuel B. Parsons. A treatise on the propagation, culture, and history of the rose. New and revised edition. In his work upon the rose, Mr. Parsons has gathered up the curious legends concerning the flower, and gives us an idea of the esteem in which it was held in former times. A simple garden classification has been adopted, and the leading varieties under each class enumerated and briefly described. The chapters on multiplication, cultivation, and training are very full, and the work is altogether one of the most complete before the public. Illustrated. Cloth, 12mo.................. 1.00

Heinrich's Window Flower Garden.

The author is a practical florist, and this enterprising volume embodies his personal experiences in Window Gardening during a long period. New and enlarged edition. By Julius J. Heinrich. Fully Illustrated. Cloth, 12mo.................................. .75

Liautard's Chart of the Age of the Domestic Animals.

Adopted by the United States Army. Enables one to accurately determine the age of horses, cattle, sheep, dogs, and pigs........... .50

Pedder's Land Measurer for Farmers.

A convenient Pocket Companion, showing at once the contents of any piece of land, when its length and width are known, up to 1,500 feet either way, with various other useful farm tables. Cloth, 18mo; .60

How to Plant and What to Do with the Crops.

With other valuable hints for the Farm, Garden and Orchard. By Mark W. Johnson. Illustrated. CONTENTS: Times for Sowing Seeds: Covering Seeds; Field Crops; Garden or Vegetable Seeds, Sweet Herbs, etc.; Tree Seeds; Flower Seeds; Fruit Trees; Distances Apart for Fruit Trees and Shrubs; Profitable Farming; Green or Manuring Crops; Root Crops; Forage Plants; What to do with the Crops; The Rotation of Crops; Varieties; Paper Covers, post-paid.......... .50

Your Plants.

Plain and Practical Directions for the Treatment of Tender and Hardy Plants in the House and in the Garden. By James Sheehan. The above title well describes the character of the work—"Plain and Practical." The author, a commercial florist and gardener, has endeavored, in this work, to answer the many questions asked by his customers, as to the proper treatment of plants. The book shows all through that its author is a practical man, and he writes as one with a large store of experience. The work better meets the wants of the amateur who grows a few plants in the window, or has a small flower Garden, than a larger treatise intended for those who cultivate plants upon a more extended scale. Price, post-paid, paper covers................ .40

Husmann's American Grape-Growing and Wine-Making.

By George Husmann of Talcoa vineyards, Napa, California. New and enlarged edition. With contributions from well-known grape-growers, giving a wide range of experience. The author of this book is a recognized authority on the subject. Cloth, 12mo............... 1.50

The Scientific Angler.

A general and instructive work on Artistic Angling, by the late David Foster. Complied by his Sons. With an Introductory Chapter and Copious Foot Notes, by William C. Harris, Editor of the "American Angler." Cloth, 12mo.. 1.50

Keeping One Cow.

A collection of Prize Essays, and selections from a number of other Essays, with editorial notes, suggestions, etc. This book gives the latest information, and in a clear and condensed form, upon the management of a single Milch Cow. Illustrated with full-page engravings of the most famous dairy cows. Recently published. Cloth, 12mo 1.00

Law's Veterinary Adviser

A Guide to the Prevention and Treatment of Disease in Domestic Animals. This is one of the best works on this subject, and is especially designed to supply the need of the busy American Farmer, who can rarely avail himself of the advice of a Scientific Veterinarian. It is brought up to date and treats of the Prevention of Disease, as well as of the Remedies. By Prof. Jas. Law. Cloth, Crown 8vo...... 3.00

Guenon's Treatise on Milch Cows.

A Treatise on the Bovine Species in General. An entirely new translation of the last edition of this popular and instructive book. By Thos. J. Hand, Secretary of the American Jersey Cattle Club. With over 100 Illustrations, especially engraved for this work. Cloth, 12mo. 1.00

The Cider Maker's Handbook.

A complete guide for making and keeping pure cider. By J. M. Trowbridge. Fully Illustrated. Cloth, 12mo........................ 1.00

Long's Ornamental Gardening for Americans.

A treatise on Beautifying Homes, Rural Districts, and Cemeteries. A plain and practical work at a moderate price, with numerous illustrations, and instructions so plain that they may be readily followed. By Elias A. Long. Landscape Architect. Illustrated. Cloth, 12mo. 2.00

The Dogs of Great Britain, America and Other Countries.

New, enlarged and revised edition. Their breeding, training and management, in health and disease; comprising all the essential parts of the two standard works on the dog, by "Stonehenge," thereby furnishing for \$2 what once cost \$11.25. Contains Lists of all Premiums given at the last Dog Shows. It Describes the Best Game and Hunting Grounds in America. Contains over One Hundred Beautiful Engravings, embracing most noted Dogs in both Continents, making together, with Chapters by American Writers, the most Complete Dog Book ever published. Cloth, 12mo............................ 2.00

Stewart's Feeding Animals.

By Elliot W. Stewart. A new and valuable practical work upon the laws of animal growth, specially applied to the rearing and feeding horses, cattle, diary cows, sheep and swine. Illustrated. Cloth, 12mo. 2.00

How to Co-operate.

A Manual for Co-operators. By Herbert Myrick. This book describes the how rather than the wherefore of co-operation. In other words it tells how to manage a co-operative store, farm or factory, and co-operative dairying, banking and fire insurance, and co-operative farmers' and women's exchanges for both buying and selling. The directions given are based on the actual experience of successful co-operative enterprises in all parts of the United States. The character and usefulness of the book commend it to the attention of all men and women who desire to better their condition. 12mo. Cloth............. 1.50

Batty's Practical Taxidermy and Home Decoration.

By Joseph H. Batty, taxidermist for the government surveys and many colleges and museums in the United States. An entirely new and complete as well as authentic work on taxidermy—giving in detail full directions for collecting and mounting animals, birds, reptiles, fish, insects, and general objects of natural history. 125 illustrations. Cloth, 12mo.......... 1.50

Stewart's Irrigation for the Farm, Garden, and Orchard.

New and Enlarged Edition. This work is offered to those American Farmers, and other cultivators of the soil, who from painful experience can readily appreciate the losses which result from the scarcity of water at critical periods. By Henry Stewart. Fully illustrated. Cloth, 12mo.......... 1.50

Johnson's How Crops Grow.

New Edition, entirely rewritten. A Treatise on the Chemical Composition, Structure, and Life of the Plant. Revised Edition. This book is a guide to the knowledge of agricultural plants, their composition, their structure, and modes of development and growth; of the complex organization of plants, and the use of the parts; the germination of seeds, and the food of plants obtained both from the air and the soil. The book is an invaluable one to all real students of agriculture. With numerous illustrations and tables of analysis. By Prof. Samuel W. Johnson, of Yale College. Cloth, 12mo.......... 2.00

Johnson's How Crops Feed.

A treatise on the Atmosphere and the Soil, as related in the Nutrition of Agricultural Plants. The volume—the companion and complement to "How Crops Grow,"—has been welcomed by those who appreciate scientific aspects of agriculture. Illustrated. By Prof. Samuel W. Johnson. Cloth, 12mo.......... 2.00

Warington's Chemistry of the Farm.

Treating with the utmost clearness and conciseness, and in the most popular manner possible, of the relations of Chemistry to Agriculture, and providing a welcome manual for those, who, while not having time to systematically study Chemistry, will gladly have such an idea as this gives them of its relation to operations on the farm. By R. Warington, F. C. S. Cloth, 12mo.......... 1.00

French's Farm Drainage.

The Principles, Process, and Effects of Draining Land, with Stones, Wood, Ditch-plows, Open Ditches, and especially with Ties; including Tables of Rainfall, Evaporation, Filteration, Excavation, Capacity of Pipes, cost and number to the acre. By Judge French, of New Hampshire. Cloth, 12mo.......... 1.50

Hunter and Trapper.

The best modes of Hunting and Trapping are fully explained, and Foxes, Deer, Bears, etc., fall into his traps readily by following his directions. By Halsey Thrasher, an old and experienced sportsman. Cloth, 12mo.......... .75

The American Merino. For Wool or for Mutton.

A practical and most valuable work on the selection, care, breeding and diseases of the Merino sheep, in all sections of the the United States. It is a full and exhaustive treatise upon this one breed of sheep. By Stephen Powers. Cloth, 12mo.......... 1.50

Armatage's Every Man His Own Horse Doctor.
By Prof. George Armatage, M. R. C. V. S. A valuable and comprehensive guide for both the professional and general reader with the fullest and latest information regarding all diseases, local injuries, lameness, operations, poisons, the dispensatory, etc., etc., with practical anatomical and surgical Illustrations. New Edition. Together with Blaine's "Veterinary Art," and numerous recipes. One large 8vo. volume, 830 pages, half morocco........................ 7.50

Dadd's Modern Horse Doctor.
Containing Practical Observations on the Causes, Nature, and Treatment of Diseases and Lameness of Horses—embracing recent and improved Methods, according to an enlightened system of Veterinary Practice, for Preservation and Restoration of Health. Illustrated. By Geo. H. Dadd, M. D. V. S., Cloth, 12mo.................... 1.50

The Family Horse.
Its Stabling, Care, and Feeding. By Geo. A. Martin. A Practical Manual, full of the most useful information. Illustrated. Cloth, 12mo.. 1.00

Sander's Horse Breeding.
Being the general principles of Heredity applied to the Business of Breeding Horses and the Management of Stallions, Brood Mares and Foals. The book embraces all that the breeder should know in regard to the selection of stock, management of the stallion, brood mare, and foal, and treatment of diseases peculiar to breeding animals. By J. H. Sanders. 12mo, cloth.................................... 2.00

Coburn's Swine Husbandry.
New, revised and enlarged edition. The Breeding, Rearing and Management of Swine, and the Prevention and Treatment of their Diseases. It is the fullest and freshest compendium relating to Swine Breeding yet offered. By F. D. Coburn. Cloth, 12mo........ 1.75

Dadd's American Cattle Doctor.
By George H. Dadd, M. D., Veterinary Practitioner. To help every man to be his own cattle-doctor; giving the necessary information for preserving the health and curing the diseases of oxen, cows, sheep, and swine, with a great variety of original recipes, and valuable information on farm and dairy management. Cloth, 12mo........... 1.50

Silos, Ensilage, and Silage.
A practical treatise on the Ensilage of Fodder Corn. Containing the most recent and authentic information on this important subject, by Manly Miles, M.D., F.R.M.S. Illustrated. Cloth 12mo........ .50

Broom Corn and Brooms.
A Treatise on Raising Broom-Corn and Making Brooms on a small or Large Scale. Illustrated. 12mo. Cloth cover................. .50

American Bird Fancier.
Or how to breed, rear, and care for Song and Domestic Birds. This valuable and important little work for all who are interested in the keeping of Song Birds, has been revised and enlarged, and is now a complete manual upon the subject. All who own valuable birds, or wish to do so, will find the new Fancier indispensable. New, revised and enlarged edition. By D. J. Browne, and Dr. Fuller Walker. Illustrated, paper cover.................................... .50

Armatage's Every Man His Own Cattle Doctor.

The Veterinary Cyclopedia—Embracing all the practical information of value heretofore published on the Diseases of Cattle, Sheep, and Swine, together with the latest and best information regarding all known diseases up to the present time. Compiled and edited by that eminent authority, Prof. George Armatage, M. R. C. V. S. One large octavo volume, 894 pages, with upwards of 350 practical illustrations, showing forms of disease and treatment. Half morocco. 7.50

Onions—How to Raise them Profitably.

Being the Practical Details, from Selection of Seed and Preparation of Ground to Harvesting and Marketing the Crop, given very plainly by Seventeen Practical Onion Growers of long experience residing in different parts of the country. No more valuable work of its size was ever issued. Paper cover, 8vo .... .20

Tobacco Culture—Full Practical Details.

This useful and valuable work contains full details of every process from the Selection and Preparation of the Seed and Soil to the Harvesting, Curing and Marketing the Crop, with illustrative engravings of the operations. The work was prepared by Fourteen Experienced Tobacco Growers, residing in different parts of the country. It also contains notes on the Tobacco Worm, with illustrations, 8vo,... .25

Hop Culture.

Plain directions given by ten experienced cultivators. Revised, enlarged and edited by A. S. Fuller. Forty engravings............ .30

Flax Culture.

A very valuable work, containing full directions, from selection of ground and seed to preparation and marketing of crop, as given by a number of experienced growers, 8vo........................ .30

Potato Pests.

No Farmer can afford to be without this little book. It gives the most complete account of the Colorado Beetle anywhere to be found, and includes all the latest discoveries as to the habits of the insect and the various means for its destruction. It is well illustrated, and exhibits in a map the spread of the insect since it left its native home. By Prof. C. V. Riley. Paper cover................................ .50

Home Fishing and Home Waters.

By Seth Green. The Utilization of Farm Streams; Management of Fish in the Artificial Pond; Transportation of Eggs and Fry, etc. Cloth, 12mo.. .50

Reed's House Plans for Everybody.

By S. B. Reed. This useful volume meets the wants of persons of moderate means, and gives a wide range of design, from a dwelling costing $250 up to $8,000, and adapted to farm, village and town residences. Nearly all of these plans have been tested by practical workings. One feature of the work imparts a value over any similar publication of the kind that we have seen. It gives an estimate of the quantity of every article used in the construction, and the cost of each article at the time the building was erected or the design made. Even if prices vary from time to time, one can, from these data, ascertain within a few dollars the probable cost of constructing any one of the buildings here presented. Profusely illustrated. Cloth, black and gold, 12mo.. 1.50

Gregory on Cabbages—How to Grow Them.

A Practical Treatise on Cabbage Culture, giving full details on every point, inclnding Keeping and Marketing the Crop. By James J. H. Gregory. Paper cover, 12mo .... .30

Gregory on Carrots, Mangold-Wurtzels, etc.

How to raise them, how to keep them, and how to feed them. By J. J. H. Gregory. Paper Cover, 12mo .... .30

Gregory on Onion Raising.

What kinds to raise, and the way to raise them. By J. J. H. Gregory. Paper cover, 12mo .... .30

Gregory on Squashes.

This Treatise, which no Farmer or Gardener ought to be without, tells all about selecting the soil for squashse; how much Manure is necessary; how to prepare and Plant; about Hoeing and Cultivating; Setting of the Fruit; Ripening, Gathering, Storing, Care during Winter, etc. By J. J. H. Gregory. Paper cover, 12mo .... .30

Hog-Raising and Pork-Making.

By Rufus Bacon Martin. The hog is reared for the money that is in him, and he represents either a profit or loss to his owner according to the treatment he receives. This pamphlet gives the personal research and experience of the author, contains many valuable suggestions, and answers many of the questions that arise in the business of hog-raising. Paper, 12mo .... .40

Fulton's Peach Culture.

This is the only practical guide to Peach Culture on the Delaware Peninsula, and is the best work upon the subject of peach growing for those who would be successful in that culture in any part of the country. It has been thoroughly revised and a large portion of it re-written, by Hon. J. Alexander Fulton, the author, bringing it down to date. Cloth, 12mo 1.50

Silk Culture.

A Handbook for Silk-Growers. By Mrs. C. E. Bamford. CONTENTS.—Chapter I. The Mulberry.—II. Gathering the Leaves.—III. The Cocoonery.—IV. Eggs of the Silk Worm Moth.—V. Feeding the Silk Worms.—VI. Moulting.—VII. Spinning.—VIII. The Cocoons.—IX. The Moths of the Silk Worm.—X. Varieties of Silk Worms.—XI. Diseases of the Silk Worm.—XII. Reeling.—XIII. Chemistry of Silk.—XIV. Miscellaneous. Paper, 12mo. Price, post-paid .... .30

Treats' Injurious Insects of the Farm and Garden. By Mrs. Mary Treat.

An original investigator who has added much to our knowledge of both Plants and insects, and those who are familiar with Darwin's works are aware that he gives her credit for important observation and discoveries. New and Enlarged Edition. With an Illustrated Chapter on Beneficial Insects. Fully illustrated. Cloth, 12mo 2.00

Fuller's Small Fruit Culturist.

By Andrew S. Fuller. Rewritten, enlarged, and brought fully up to the present time. The book covers the whole ground of propagating small fruits, their culture, varieties, packing for market, etc. It is very finely and thoroughly illustrated, and makes an admirable companion to "The Grape Culturist," by the same well known author. 1.50